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Introduction

Social development and different regional growth trends have produced dramatic shifts in the global landscape of science and engineering (S&E) research, education, and business activities. An increasingly multipolar world for S&E is emerging after many decades of leadership by the United States, the European Union, and Japan. This overview presents the changing picture of the world of S&E by highlighting activities in which the developing world is approaching parity with the developed world, activities in which the developed world maintains preeminence, and also activities in which smaller nations have emerged as prominent contributors.

The international and domestic S&E trends that *Science and Engineering Indicators* describes can be understood in light of the worldwide trend toward more knowledge-intensive economies and increasing global collaboration and competition in S&E. In knowledge-intensive economies, S&E research, its commercial utilization, and other intellectual work are of growing importance. Wide access to education as well as to information and communication technologies (ICT) produces technologically empowered populations. Such economies rely on a skilled workforce and on sustained investment in research and development to produce knowledge streams that form the core of knowledge-intensive production in the manufacturing (e.g., spacecraft, pharmaceuticals, computers) and services (e.g., financial, business, education, health) industries. The goods and services of these industries, many of them new in this century, have developed markets that did not exist previously; these goods and services help nations integrate and compete in the global marketplace. International trade, supplier chains, and global infrastructure tie this global marketplace together.

Rapid growth rates frequently accompany the early stages of economic and technical development, but they slow as societies mature (Price 1963). As developing nations focus resources in R&D, education, and knowledge-intensive production and trade, their initially rapid growth rates in these areas can exceed those of developed nations and allow some of them to approach the capabilities of the developed world.

This overview is not intended to be comprehensive; instead, it highlights information in *Science and Engineering Indicators* that offers insights into major global trends. The focus is on broad comparisons in indicators across countries, economies, and regions that cover S&E training, research outputs, the creation and use of intellectual property, and the output of knowledge-intensive industries. More detailed findings on particular topics can be found in the “Highlights” sections that appear at the beginning of chapters 1–7.[i]

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[i] The indicators included derive from a variety of national, international, public, and private sources and are not always strictly comparable in a statistical sense. In addition, the metrics and models relating them to each other and to economic and social outcomes need further development. Individual data points and findings should be interpreted with care.

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Science and Technology in the World Economy

Workers with S&E Skills

In the increasingly interconnected world of the 21st century, workers with S&E skills are integral to a nation's innovative capacity and economic competitiveness. Governments in many countries have made increased access to S&E-related postsecondary education a high priority. At the same time, they are faced with increased mobility of high-skill workers, including those educated or employed in S&E fields, as countries compete to attract the best talent (OECD 2012:54). Comprehensive and internationally comparable data on the global S&E workforce, while limited, suggest that work requiring S&E skills is occurring throughout the world, with concentrations in specific regions.

S&E degrees, important for an innovative knowledge economy, have become relatively more prevalent in some Asian countries than in the United States: in China, nearly half of all first university degrees (49%) awarded in 2012 were in S&E, compared with 33% in the United States. Globally, the number of first university degrees in S&E reached about 6.4 million, according to the most recent estimates. Almost half of these degrees were conferred in China (23%) and India (23%); another 21% were conferred in the European Union (EU; see "Glossary" for member countries) (12%) and in the United States (9%) (Figure O-1).

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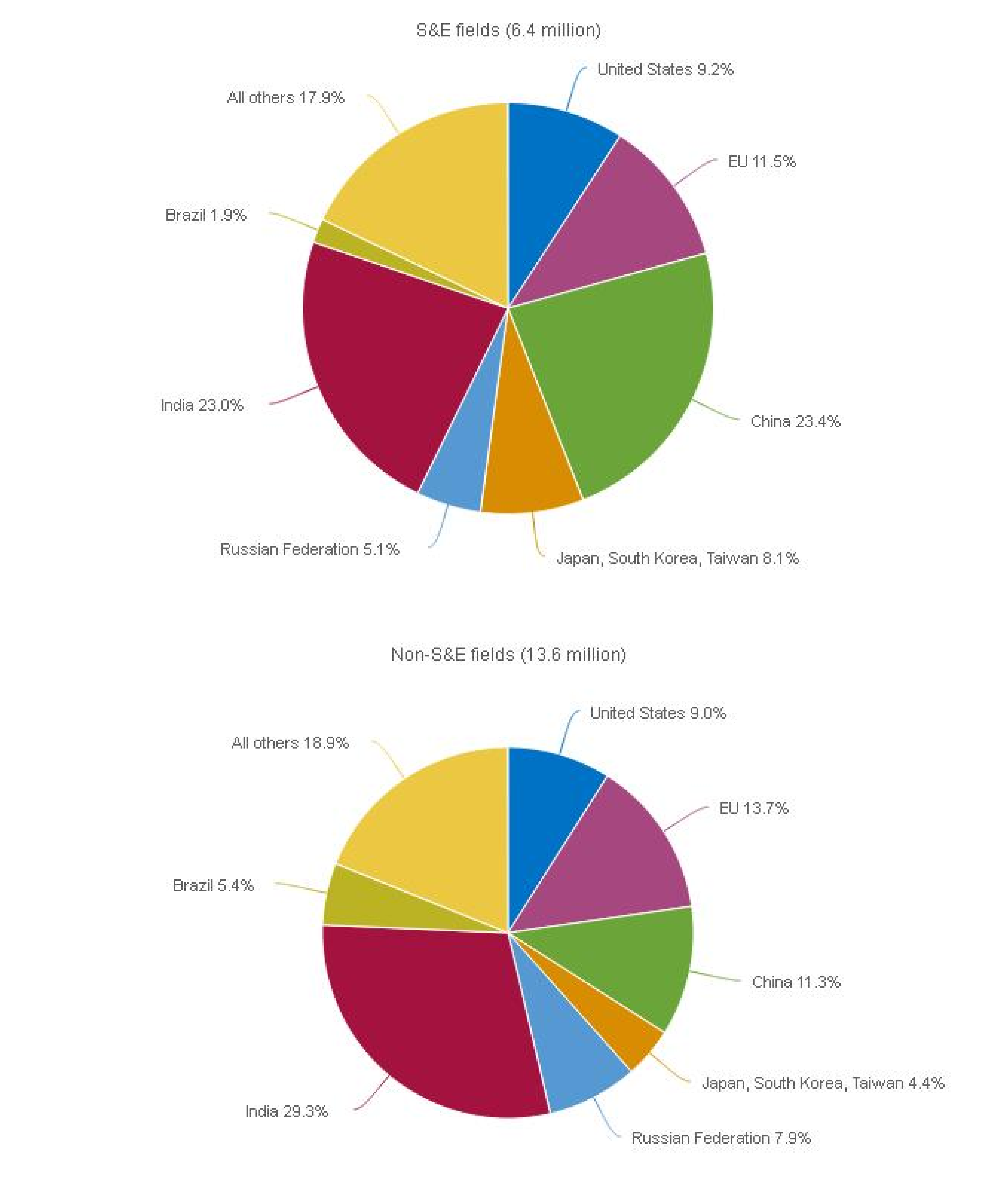
Figure O-1

First university degrees, by selected region/country/economy: 2012



EU = European Union.

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SOURCES: Organisation for Economic Co-operation and Development, Education Online database, http://www.oecd.org/education; national statistical offices.

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University degree production in China has grown faster than in major developed nations and regions. Between 2000 and 2012, the number of S&E bachelor's degrees awarded in China rose more than 300%, significantly faster than in the United States and in many other European and Asian regions and economies (Figure O-2). Additionally, during the same period, the number of non-S&E degrees conferred in China also rose dramatically (by 1,000%), suggesting that capacity building in China, as indicated by bachelor's degree awards, is occurring in both S&E and non-S&E areas. In fact, the S&E proportion of all first university degrees decreased significantly in China, from 73% in 2000 to 49% in 2012. In other major economies, this proportion has fluctuated within a relatively narrow range.

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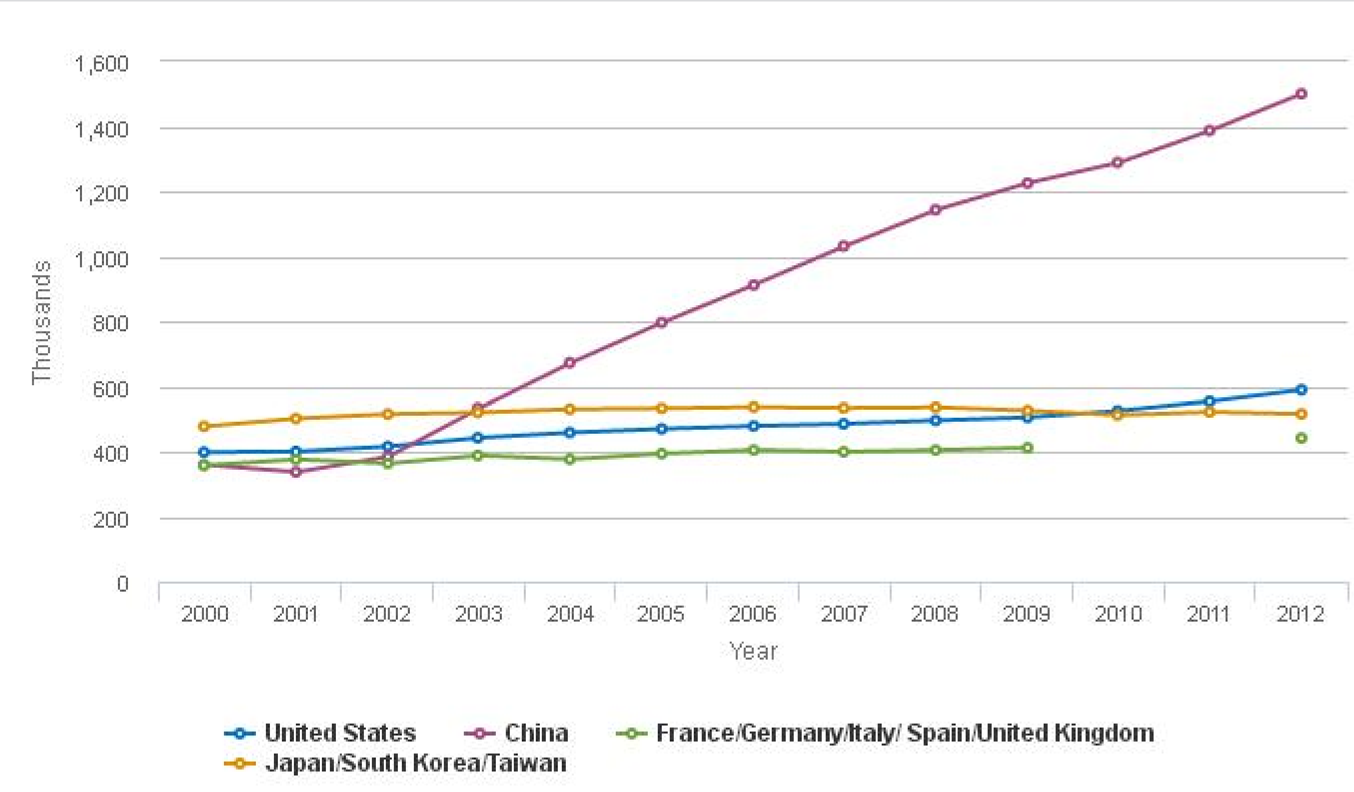
Figure O-2

S&E first university degrees, by location: 2000–12



NA = not available.

NOTE: Data are not available for all locations in all years.

SOURCES: Organisation for Economic Co-operation and Development, Education Online database, http://www.oecd.org/education; national statistical offices.

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Understanding the relationship between degrees conferred in a country and the capabilities of its workforce is complicated by the fact that increasing numbers of students are receiving higher education outside their home countries.[i] The United States remains the destination of choice for the largest number of internationally mobile students worldwide. The number of such students enrolled in the United States rose from 475,000 in 2000 to 784,000 in 2013. Yet, due to efforts by other countries to attract more foreign students, the share of the world's internationally mobile students enrolled in the United States fell from 25% in 2000 to 19% in 2013. Other popular destinations for internationally mobile students are the United Kingdom, Australia, France, and Germany (Figure O-3).

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[i] An additional complexity, as data from the United States show, is that a direct correlation often does not exist between an individual's study field of degree and occupation. S&E degree holders report applying their S&E expertise in a wide variety of occupations, including S&E and non-S&E occupations. This indicates that the

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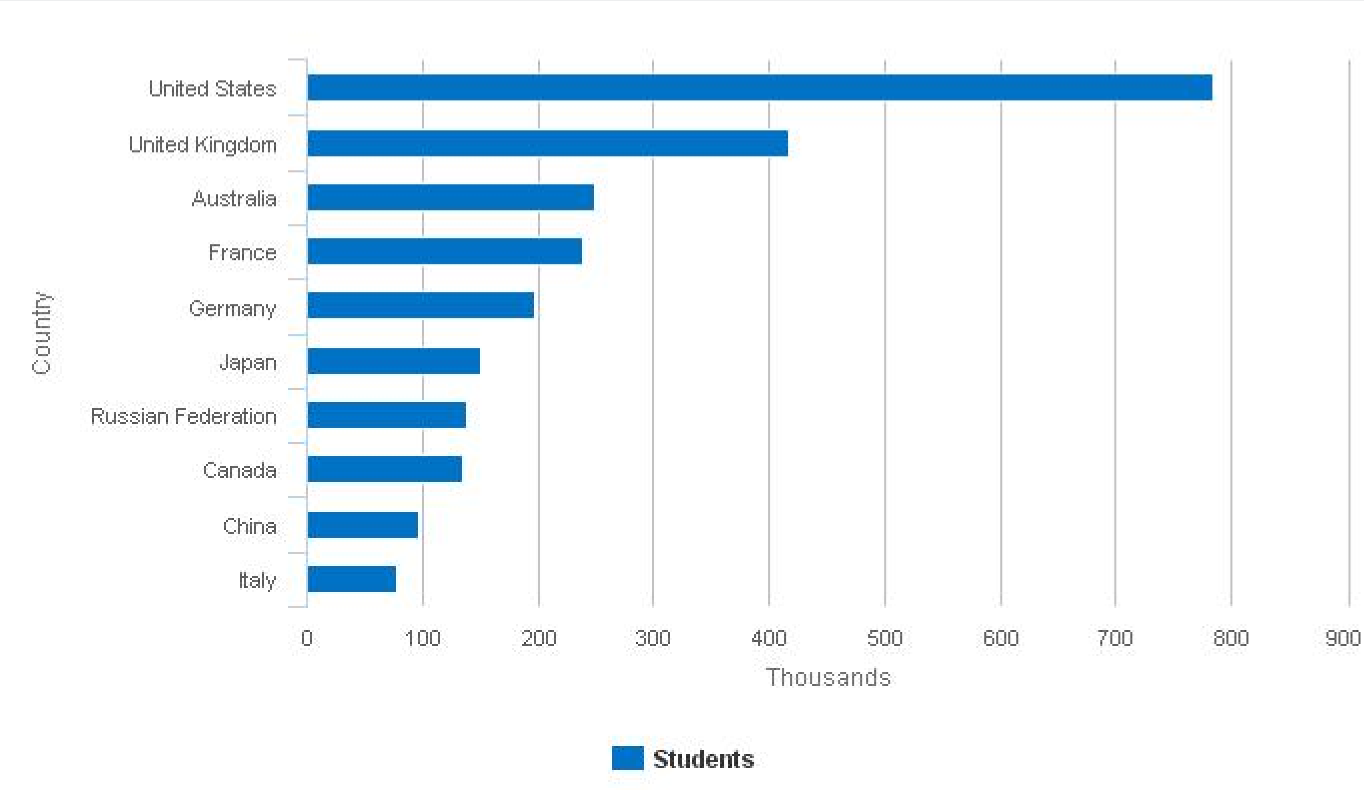
application of S&E knowledge and skills is widespread across the technologically sophisticated U.S. economy and not just limited to occupations classified as S&E. For more information on this and the U.S. S&E workforce, see National Science Board (2015).

Overview

Figure O-3

Internationally mobile students enrolled in tertiary education, by selected region/country/economy: 2013



NOTES: Data are based on the number of students who have crossed a national border and moved to another country with the objective of studying (i.e., mobile students). Data for Canada, Italy, and Japan correspond to 2012.

SOURCE: United Nations Educational, Scientific and Cultural Organization Institute for Statistics database, special tabulations (2015).

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Graduate education in the United States remains particularly attractive to international students. Unlike S&E bachelor's-level degrees, the United States awards a larger number of S&E doctorates than China (Figure O-4). However, a substantial proportion of U.S. S&E doctoral degrees are conferred to international students with temporary visas. In 2013, temporary visa holders, not counting foreign-born students with permanent visas, earned 37% of S&E doctoral degrees. Temporary visa holders are particularly concentrated in engineering, computer sciences, and economics; in 2013, temporary residents earned half or more of the doctoral degrees awarded in these fields. Overall, nearly half of the post-2000 increase in U.S. S&E doctorate production reflects degrees awarded to temporary visa holders, mainly from Asian countries such as China and India. If past trends continue, however, a majority of the S&E doctorate recipients with temporary visas—more than 60%—will remain in the United States for subsequent employment.

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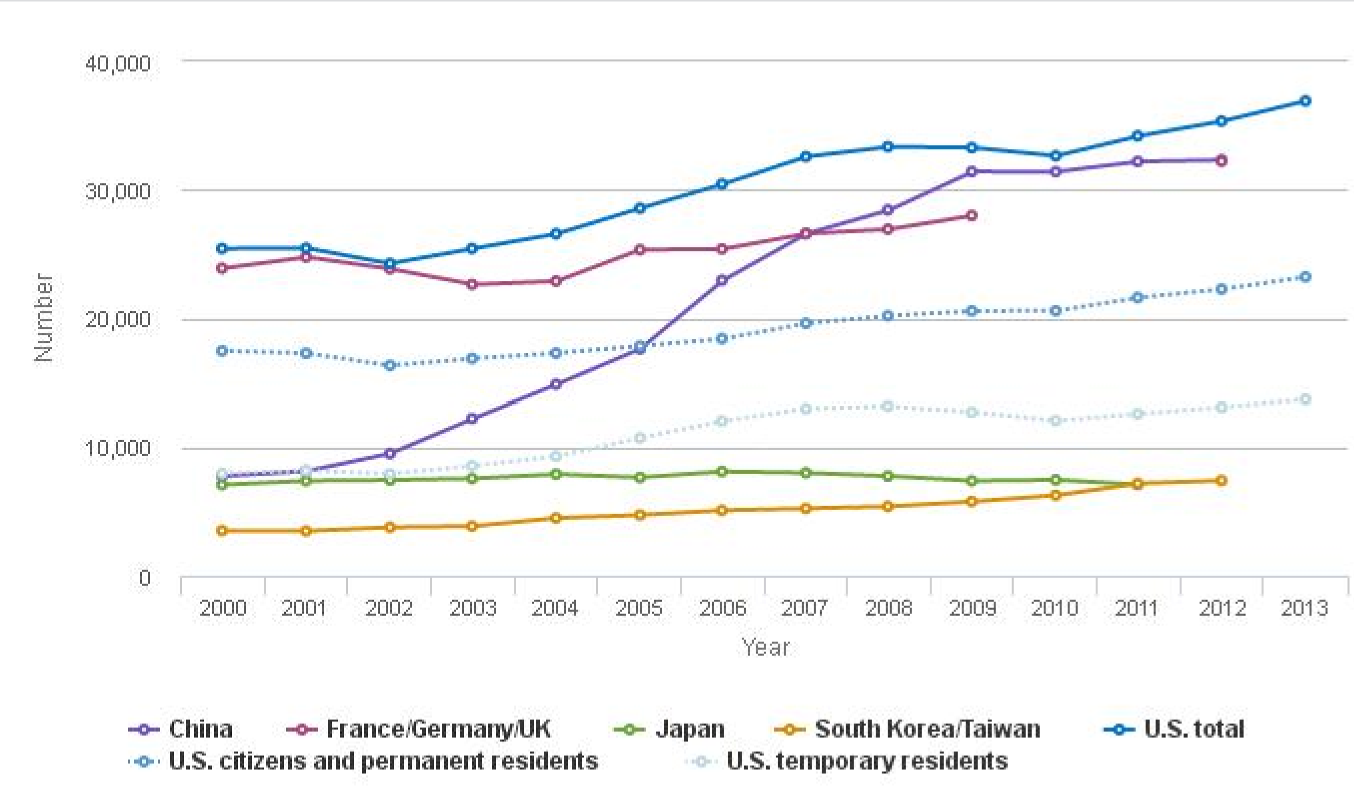
Figure O-4

Doctoral degrees in S&E, by selected region/country/economy: 2000–13



NA = not available.

UK = United Kingdom.

NOTE: Data are not available for all regions/countries/economies in all years.

SOURCES: Organisation for Economic Co-operation and Development, Education Online database, http://www.oecd.org /education; national statistical offices.

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These doctorate recipients add to the most highly trained segment of the international S&E workforce, whose size cannot readily be estimated using fragmentary data. Comprehensive, internationally comparable data on the worldwide S&E workforce is very limited, making it difficult to analyze the precise size of this workforce. However, the Organisation for Economic Co-operation and Development (OECD) provides international estimates on one particularly salient component of this workforce, researchers, who are defined as “professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned” (OECD 2002:93). Although national differences in these estimates may be affected by survey procedures and interpretations of international statistical standards, they can be used to describe broad national and international trends of this highly specialized component of the larger S&E workforce.

The United States and the EU continue to enjoy a distinct but decreasing advantage in the supply of human capital for research. In absolute numbers, these two regions had some of the largest populations of researchers at the latest count, but China has been catching up (Figure O-5).

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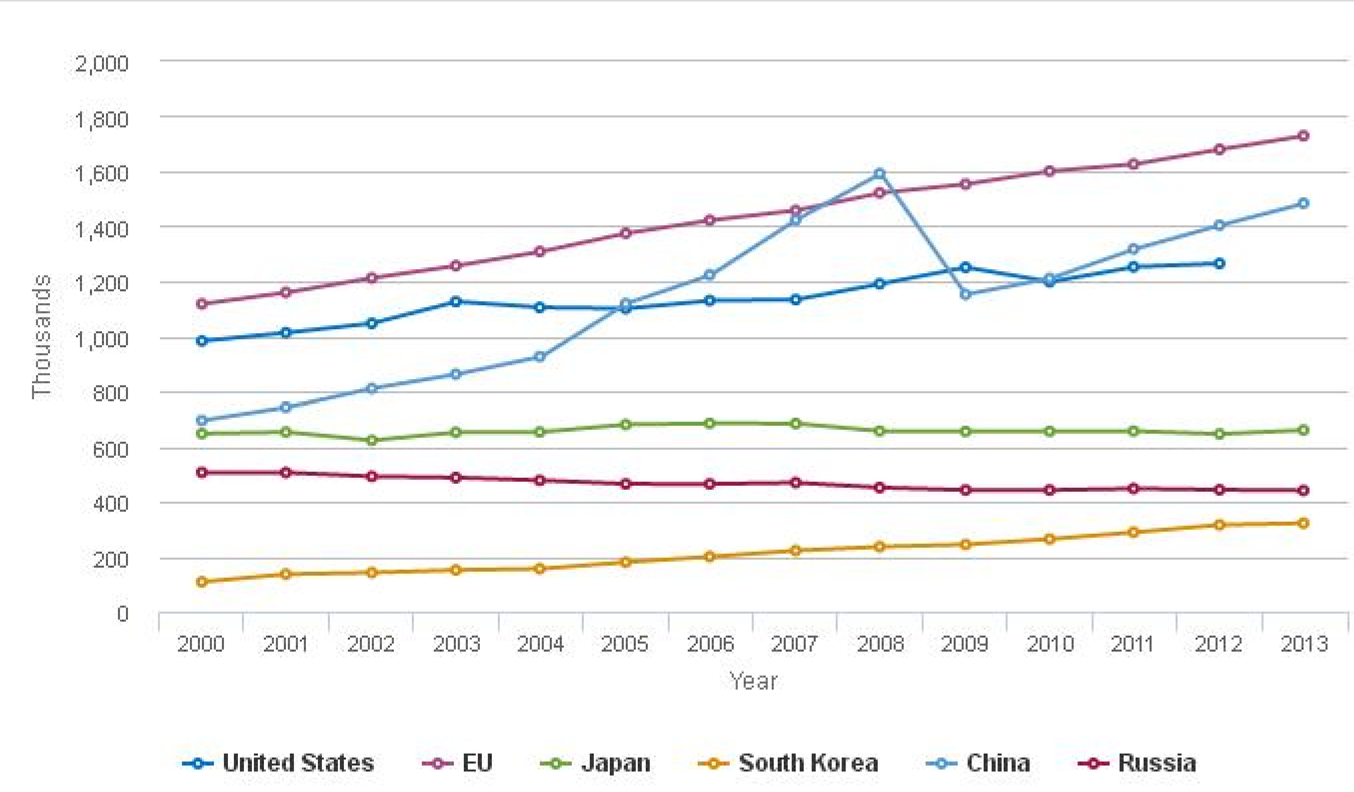
Figure O-5

Estimated number of researchers in selected regions/countries/economies: 2000–13



NA = not available.

EU = European Union.

NOTES: Data are not available for all regions/countries/economies for all years. Researchers are full-time equivalents. Counts for China before 2009 are not consistent with Organisation for Economic Co-operation and Development (OECD) standards. Counts for South Korea before 2007 exclude social sciences and humanities researchers.

SOURCE: OECD, *Main Science and Technology Indicators* (2015/1), http://www.oecd.org/sti/msti.htm.

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The worldwide total of workers engaged in research has been growing rapidly, and growth has been more robust in parts of Asia. The most rapid expansion has occurred in South Korea, which nearly doubled its number of researchers between 2000 and 2006 and continued to grow strongly thereafter, and in China, which reported more than twice the number of researchers in 2008 compared with 2000 and likewise reported substantial growth in later years. (China's pre-2009 data did not correspond to the OECD definition and are therefore not comparable to China's data for 2009 onward.) The United States and the EU experienced steady growth at lower rates, with a 29% increase in the United States between 2000 and 2012 and a 55% increase in the EU between 2000 and 2013. Exceptions to the worldwide trend included Japan (which remained relatively flat) and Russia (which experienced a decline).

Researchers measured as a share of employed persons is another indicator of national competitiveness in a globally integrated knowledge economy. Several economies in Asia have shown a sustained increase in that statistic over

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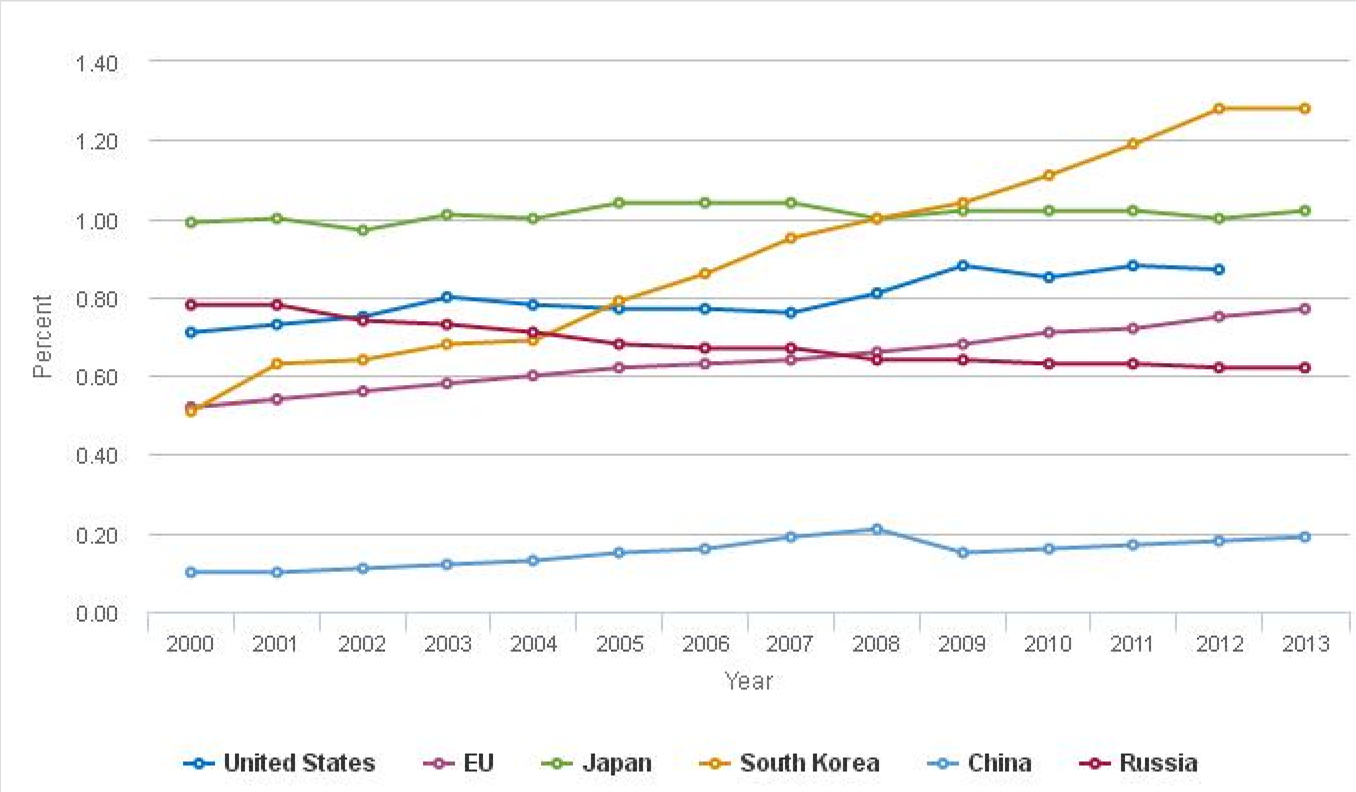
time. Foremost among them is South Korea (Figure O-6), but growth is also evident in Singapore, Taiwan, and China. Although China reported a large number of researchers, these workers represent a much smaller percentage of China's workforce (0.19%) than in the United States, EU, South Korea, and Japan (Figure O-6).

Figure O-6

Researchers as a share of total employment in selected regions/countries/economies: 2000–13



NA = not available.

EU = European Union.

NOTES: Data are not available for all regions/countries/economies for all years. Researchers are full-time equivalents. Counts for China before 2009 are not consistent with Organisation for Economic Co-operation and Development (OECD) standards. Counts for South Korea before 2007 exclude social sciences and humanities researchers.

SOURCE: OECD, *Main Science and Technology Indicators* (2015/1), http://www.oecd.org/sti/msti.htm.

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R&D Performance

The rising number of researchers and their growing share of the labor force are reflected in strong and widespread growth in R&D expenditures. The worldwide estimated total of R&D expenditures continues to rise at a significant pace, doubling over the 10-year period between 2003 and 2013. While the global trends toward more knowledge- and technology-intensive economies are continuing, countries vary in their R&D intensity, their relative focus on early versus later stages of R&D, and their dependence on the business sector for R&D funding.

Notwithstanding their overall growth, global R&D expenditures continue to be concentrated in North America, Europe, and East and Southeast Asia (Figure O-7). Among individual countries, the United States is by far the largest performer in R&D, followed by China, whose R&D spending is nearing that of the EU total (Figure O-8).

Overview

Together, the United States and China accounted for almost half of the estimated $1.67 trillion in global R&D in 2013. Japan is third, at 10%, and Germany is fourth, at 6%. South Korea, France, Russia, the United Kingdom, and India make up the next tier of performers—each accounting for 2%–4% of the global R&D total.

Figure O-7

Global R&D expenditures, by region: 2013

PPP = purchasing power parity.

NOTES: Foreign currencies are converted to dollars through PPPs. Some country data are estimated. Countries are grouped according to the regions described by *The World Factbook*, www.cia.gov/library/publications/the-world-factbook/.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics estimates, August 2015. Based on data from the Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2015 /1); and the United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, http:/ /www.uis.unesco.org/DataCentre/Pages/BrowseScience.aspx, accessed 23 January 2015.

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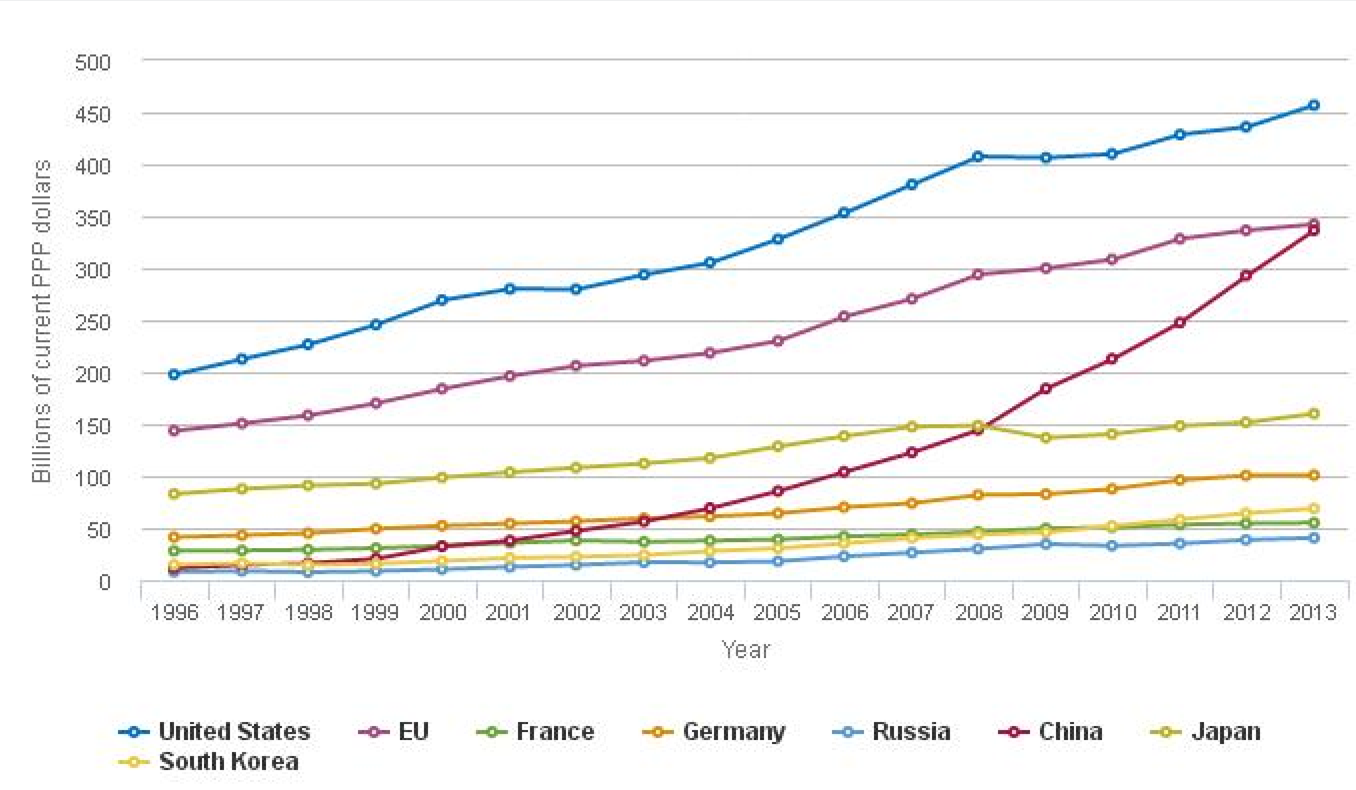
Figure O-8

Gross domestic expenditures on R&D, by the United States, EU, and selected other countries: 1996–2013



EU = European Union; PPP = purchasing power parity.

NOTES: Data are for the top seven R&D-performing countries and the EU. Data for the United States in this figure reflect international standards for calculating gross expenditures on R&D, which vary slightly from the National Science Foundation's (NSF's) protocol for tallying U.S. total R&D.

SOURCES: NSF, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2015/1); and United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, http://www.uis.unesco.org /DataCentre/Pages/BrowseScience.aspx, accessed 23 January 2015.

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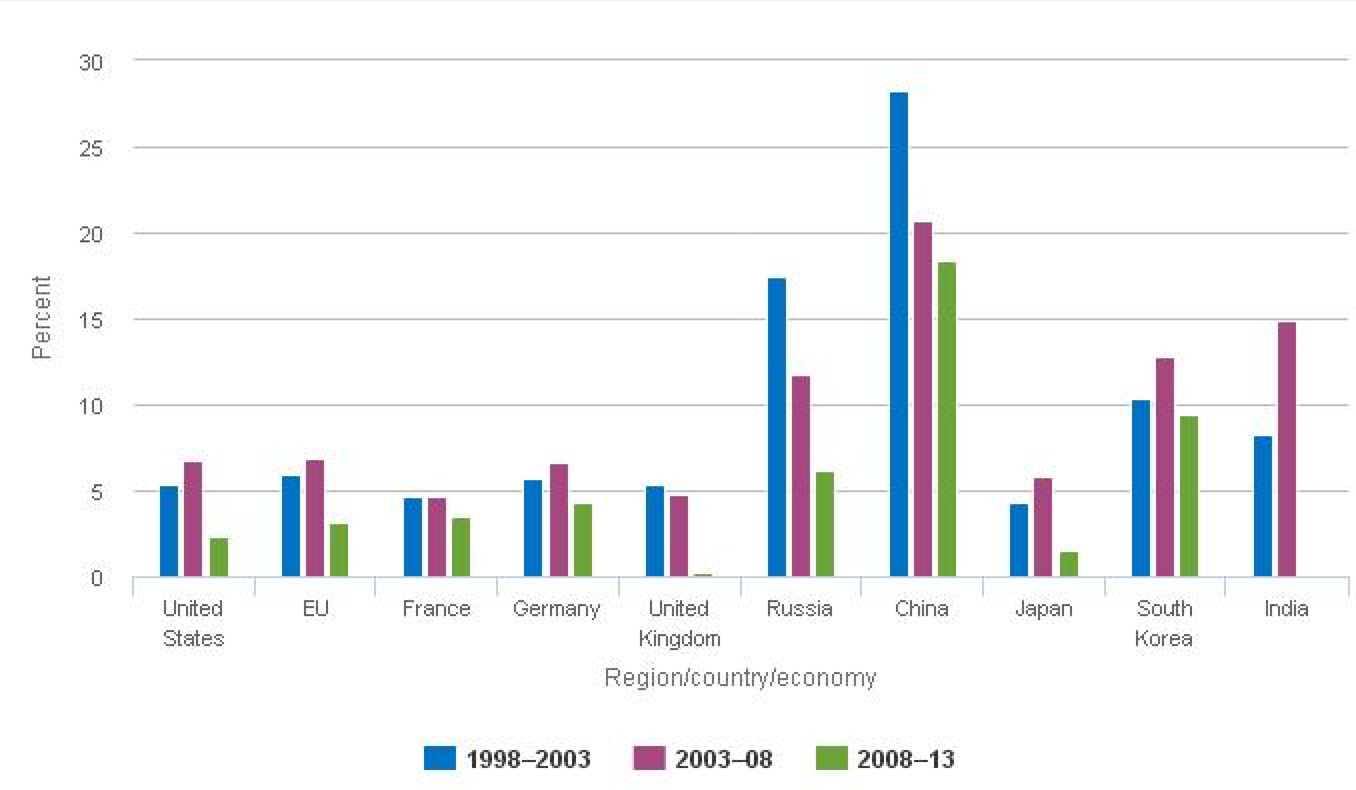
A notable trend over the past decade has been the growth in R&D spending in East and Southeast Asia compared to the other major R&D performing areas. China continues to display the most vigorous R&D growth (Figure O-9), accounting for about one-third of the global increase in R&D spending over the 2003–13 period. These differences in growth rates led to substantial share losses for both the United States (from 35% to 27%) and Europe (from 27% to 22%). During the same period, the combined share of the East and Southeast Asian economies—including China, Japan, Malaysia, Singapore, South Korea, and Taiwan—rose from 25% to 37% of the global total.

Overview

Figure O-9

Average annual growth in gross domestic expenditures on R&D for the United States, EU, and selected other countries: 1998–2013



NA = not available.

EU = European Union.

NOTES: Data are for the top nine R&D-performing countries and the EU. International data on gross domestic expenditures on R&D measured in foreign currencies are converted into U.S. dollars using purchasing power parity exchange rates. Data are not available for all countries for all years. Data for the United States in this figure reflect international standards for calculating gross expenditures on R&D, which vary slightly from the National Science Foundation's (NSF's) protocol for tallying U.S. total R&D.

SOURCES: NSF, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2015/1); and United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, http://www.uis.unesco.org/DataCentre/Pages/BrowseScience.aspx, accessed 23 January 2015.

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The share of total R&D spending relative to the size of the economy is often used as a convenient indicator of innovative capacity. Although the United States invests far more in R&D than any other individual country, several other, smaller economies have greater *R&D intensity*—that is, a higher ratio of R&D expenditures to gross domestic product (GDP). A stated goal by the EU (one of the five targets for the EU in 2020 [EC 2013]) is to achieve a 3% R&D-to-GDP ratio. In 2013, the United States had an R&D intensity of 2.7% (Figure O-10). Israel and South Korea are essentially tied for the top spot, with ratios of 4.2% each. Over the past decade, the ratio has fluctuated within a relatively narrow range in the United States and rose gradually in the EU as a whole; in South Korea—and particularly in China, which started with a low base—the R&D-to-GDP ratio rose substantially, nearly doubling in both countries in the last 10 years (Figure O-10).

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The use of this indicator in policymaking has its limitations. Governments have limited control over the size of their economies and over annual R&D spending, which makes achieving a specific R&D-to-GDP ratio a matter of some chance, magnified by the fact that businesses tend to be a leading source of R&D funding. In the United States, businesses funded about 61% of all U.S. R&D in 2013. While the corresponding business sector shares are higher, around 75%, in China, Japan, and South Korea and about the same or lower in Germany (66%), France (55%), United Kingdom (47%), and Russia (28%), they complicate achieving a specific R&D-to-GDP target.

The production sectors supported by business R&D also vary across countries. The manufacturing sector accounts for about 86%–88% of business R&D in Germany, Japan, South Korea, and China—considerably higher than in the United States (69%), France (50%), and the United Kingdom (40%). In the United States, business R&D is spread broadly across manufacturing and services categories: computer, electronic, and optical products; pharmaceuticals; air and spacecraft; information and communication services, including software publishing; and professional, scientific, and technical services including R&D services.

Countries also vary in their relative focus on basic research, applied research, and (experimental) development.[i] In 2012, China spent only 5% of its R&D funds, compared to 17% in the United States, on *basic research*—work aimed at gaining comprehensive knowledge or understanding of the subject under study without specific applications in mind. On the contrary, China spent 84% of its R&D funds, compared to 62% in the United States, on *development*—work that is directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes. The lack of specific applications as a goal introduces an element of risk and uncertainty in basic research, which is why a substantial amount of basic research is typically funded by the government. China's more limited focus on basic research may reflect the large business sector role in R&D funding as well as the opportunity to build on basic research done elsewhere (Qui 2014).

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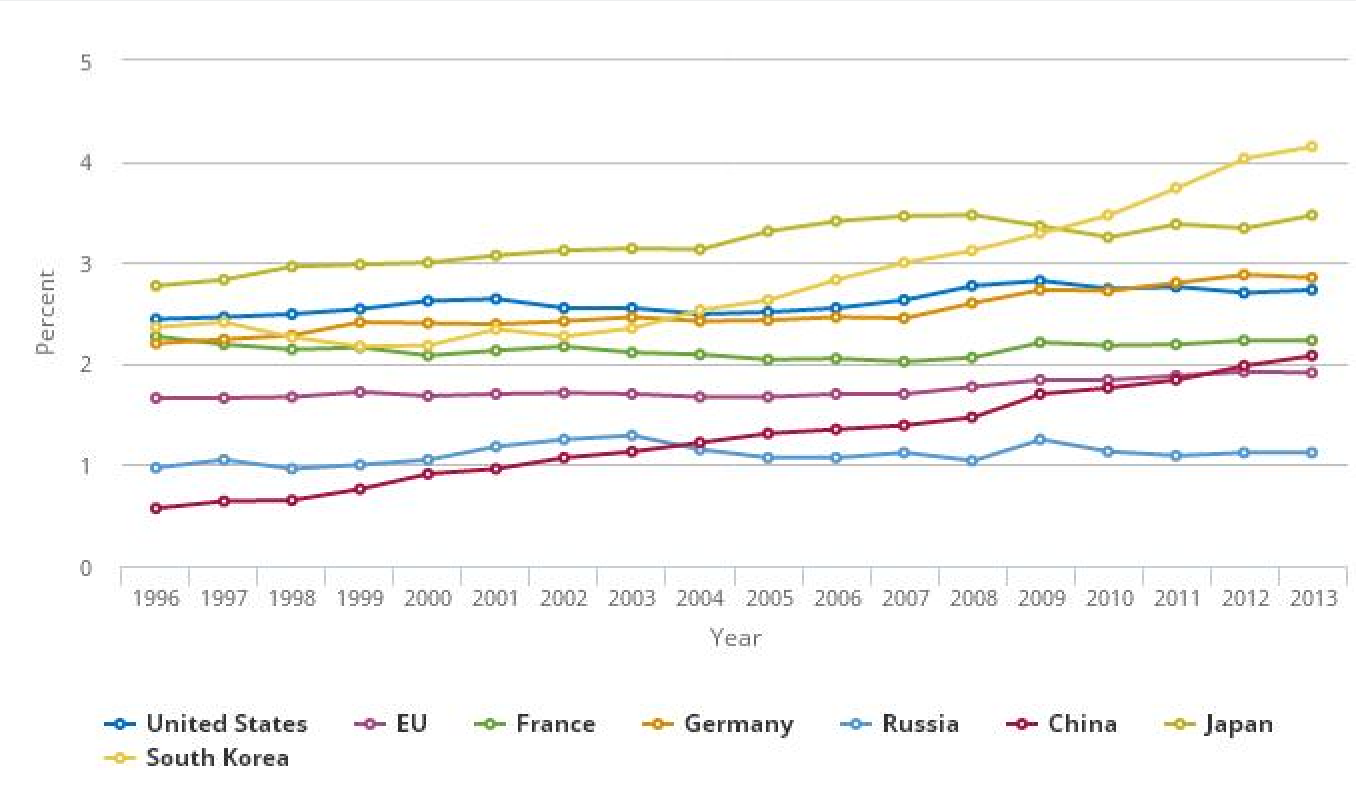
[i] These terms are defined in the chapter "Glossary."

Figure O-10

Gross domestic expenditures on R&D as a share of GDP for the United States, EU, and selected other countries: 1996–2013



EU = European Union; GDP = gross domestic product.

NOTES: Data are for the top seven R&D-performing countries and the EU. Data for the United States in this figure reflect international standards for calculating gross expenditures on R&D, which vary slightly from the National Science Foundation's (NSF's) protocol for tallying U.S. total R&D.

SOURCES: NSF, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series); Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators* (2015/1); and United Nations Educational, Scientific and Cultural Organization Institute for Statistics Data Centre, http://www.uis.unesco.org /DataCentre/Pages/BrowseScience.aspx, accessed 23 January 2015.

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Research Publications

Research produces new knowledge; refereed S&E publications are one of the tangible measures of research activity that have been broadly available for international comparison. The United States, the EU, and the developed world produce the majority of refereed S&E publications. However, similar to the trends for researchers and R&D spending, S&E research output in recent years has grown much more rapidly in China and other developing countries when compared with the output of the United States and other developed countries. China's global share of S&E publications tripled from 6% in 2003 to 18% in 2013. As a result, China's share is now comparable—in terms of the number of publications—to that of the United States (Figure O-11). Research output has also grown rapidly in other developing countries, particularly Brazil and India.

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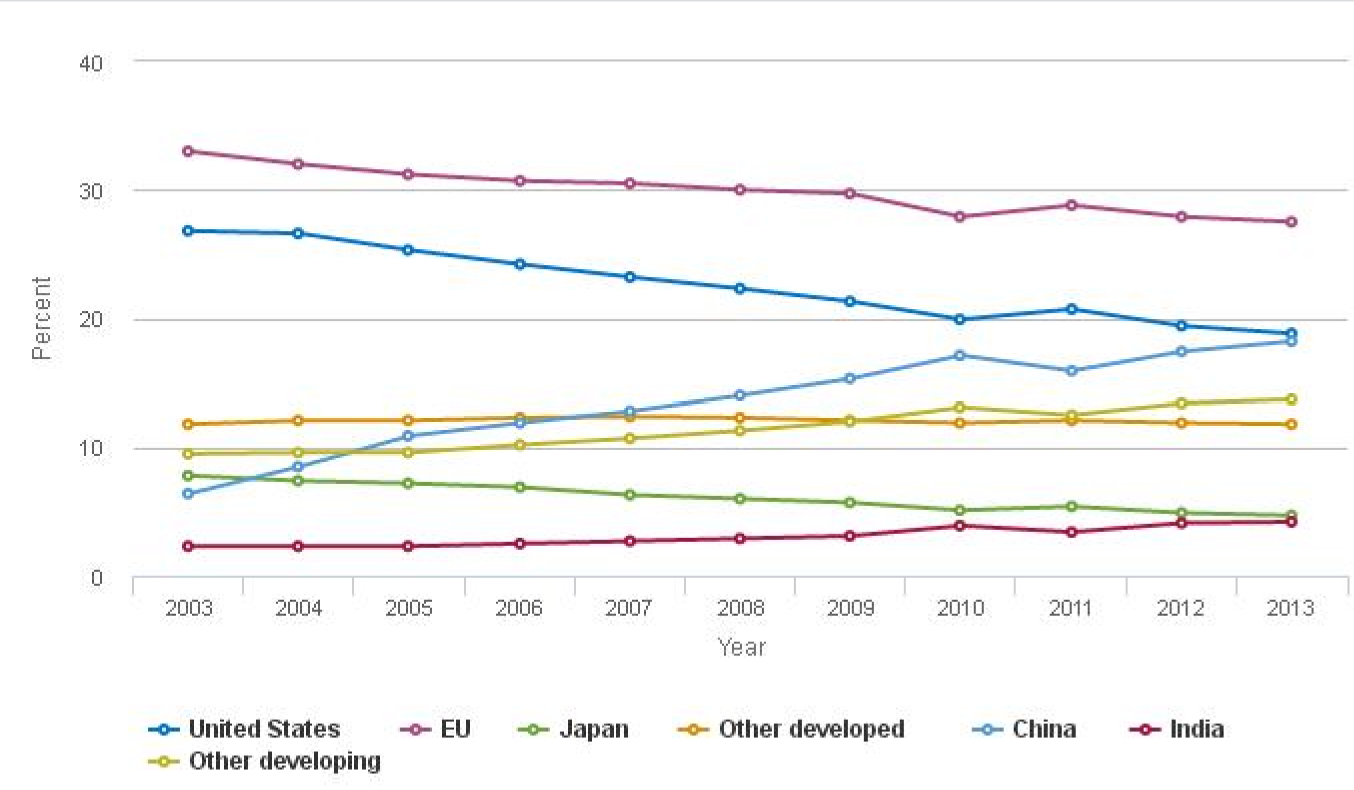
Figure O-11

S&E articles, by global share of selected region/country/economy: 2003–13



EU = European Union.

NOTES: Publication counts are from a selection of journals, books, and conference proceedings in S&E from Scopus. Publications are classified by their year of publication and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles from multiple countries/economies, each country/economy receives fractional credit on the basis of the proportion of its participating authors). Some publications have incomplete address information for coauthored publications in the Scopus database and cannot be fully assigned to a country or economy. These unassigned counts, 1% of the world total in 2013, are used to calculate this figure but are not shown. See appendix table 5-26.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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The subject matter emphasis of scientific research varies somewhat across geographic locations. In 2013, the United States and the EU produced significant shares of the worldwide biomedical sciences (biological sciences, medical sciences, and other life sciences) articles, each larger than China's share. However, China produced a significant share of the worldwide total of engineering articles, larger than the share of the United States and the EU.

When researchers in one country cite the published work of researchers in another country, the resulting citation patterns are an indication of knowledge flows across regions. These patterns are influenced by cultural, geographic, and language ties as well as perceived impact. All other things being equal, researchers are more likely to cite work written in their native language. U.S. articles are disproportionately cited by Canadian and United Kingdom authors.

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In comparison, U.S. authors cite Chinese articles less than would be expected based on the overall number of global citations to Chinese articles. These factors notwithstanding, citations to refereed articles and presentations are an oft-used indicator of the impact of research output.

U.S. publications receive the largest absolute number of citations; when adjusted for the size of each country's research pool, it joins in this measure with Canada, Switzerland, the Nordic countries, and the United Kingdom in setting the bar in the production of influential research articles. The impact of EU publications is also enhanced by recent improvement in citations for the relatively new members of the EU: Hungary, Poland, Romania, Slovakia, and Slovenia.

One measure of the influence of a country's or region's research is its share of the world's top 1% of cited articles compared to what would be expected based on the size of each country's pool of S&E publications. With this measure, if a country's share is exactly what would be expected based on size, the percentage is 1%. The U.S. percentage has held fairly steady at about twice the expected value (1.8%–1.9%), while the percentage of articles from the EU in the top 1% grew from 1.0% to 1.3% between 2001 and 2012 (Figure O-12). China's share of this top 1%, starting from a low base, almost doubled in the same period, from 0.4% to 0.8%.[i]

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[i] The implications of these differences in top citations should be drawn with care because the data used for the analysis require that article abstracts are provided in the English language. Many publications from China have English-language abstracts but Chinese-language text, limiting their accessibility and likelihood of citation for researchers not fluent in Chinese.

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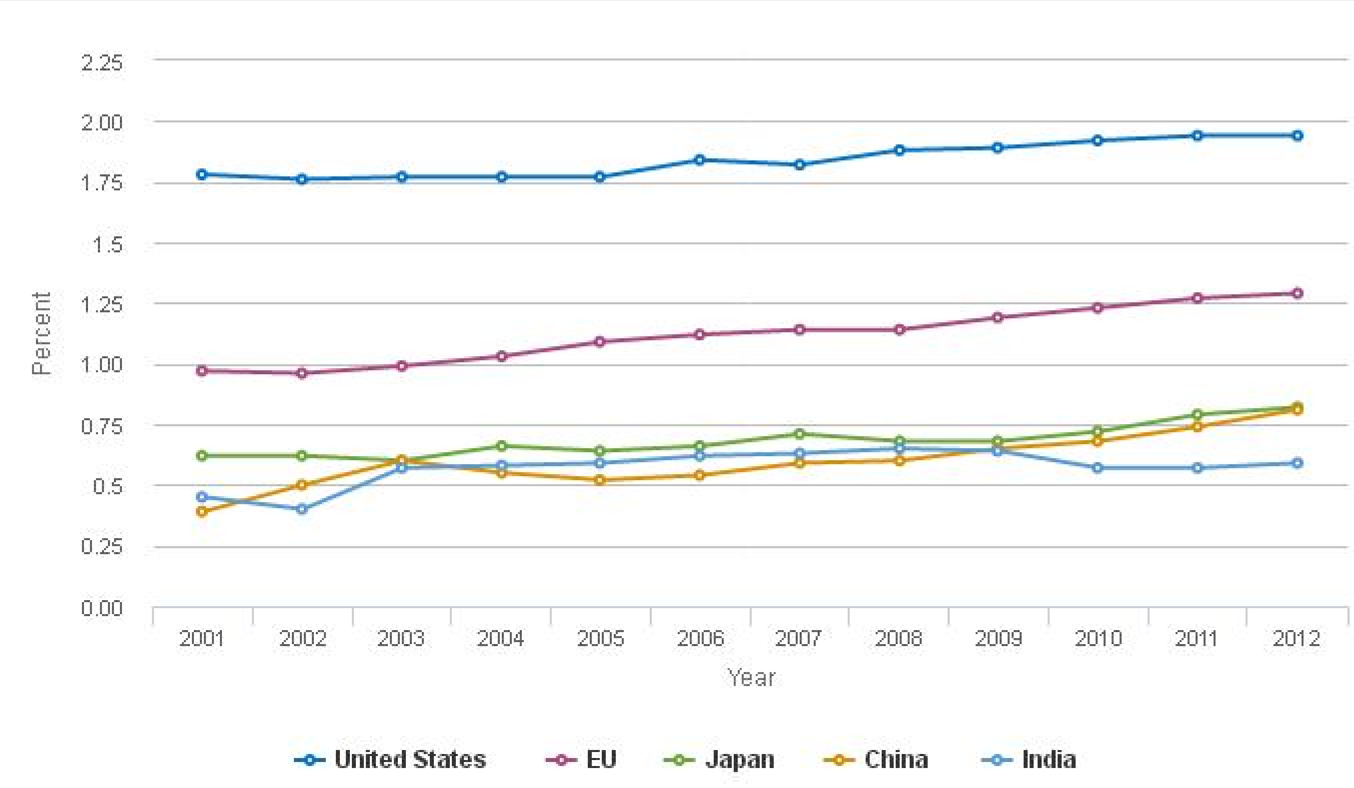
Figure O-12

Share of U.S., EU, Japan, China, and India S&E articles that are in the world's top 1% of cited articles: 2001–12



EU = European Union.

NOTES: The figure depicts the share of publications that are in the top 1% of the world's citations, relative to all the country's publications in that period and field. It is computed as follows: *Sx* = *HCPx*/*Px*, where *Sx* is the share of output from country *x* in the top 1% most-cited articles; *HCPx* is the number of articles from country *x* that are among the top 1% most-cited articles in the world; and *Px* is the total number of papers from country *x* in the database that were published in 2012 or earlier. Citations are presented for the year of publication, showing the counts of subsequent citations from peer-reviewed literature. At least 3 years of data following publication are needed for a meaningful measure. Publications that cannot be classified by country or field are excluded. Articles are classified by the publication year and assigned to a country/economy on the basis of the institutional address(es) listed in the article. See appendix table 5-25 for countries/economies included in the EU. The world average stands at 1.00% for each period and field.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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Collaboration on S&E publications between authors of different countries has been increasing in recent years, reflecting an increased pool of trained researchers, improvements in communication technologies, and the growing international mobility of researchers. Other drivers include budget pressures on R&D spending that increase the incentives for collaboration and sharing resources and also the need to coordinate globally on challenges like climate change, infectious diseases, and the allocation of scarce natural resources (Wagner, Park, and Leydesdorff 2015).

Indicators of Innovation and Intellectual Property

Overview

S&E research and the scientific and technological knowledge produced thereby are an important, though incomplete, part of the overall innovation process (Pavitt 2005). This relationship, combined with the role of innovation as an important contributor to economic growth, drives interest in internationally comparable measures of innovation. The international standard for innovation measurement defines innovation as “the implementation of a new or significantly improved product or process, a new marketing method, or new organizational method” (OECD/Eurostat 2005:46–7). Despite this agreed standard, internationally comparable data on innovation are limited. Starting in 2008, the National Science Foundation’s Business R&D and Innovation Survey provides data for the United States on the share of companies that report innovative activities. These data currently allow for cross-industry comparability within the United States. [i]

When the results of S&E research, innovative activity, or other intangibles are granted legal protection that allows their owners the right to prevent others from benefitting from their use, these intangibles are considered to be *intellectual property.* Patenting confers the rights of property to novel, useful, and nonobvious inventions for a specified period of time. While academic studies question the strength of the link between patents and innovation, strengthening of intellectual property regimes has been found to promote foreign investment, which may in turn provide a pathway for knowledge flows (Boldrin and Levine 2013). Although the propensity to patent varies across technology areas and many patents do not become commercialized or lead to practical innovations, patent grants and applications are a broad partial indicator of invention, an activity that is an important part of the innovation process.

Existing indicators in this area show dominance in the developed world, with notable growth (albeit from low bases) in the Asian economies. The United States Patent and Trademark Office (USPTO) grants patents to inventors worldwide. These patents are increasingly granted to inventors outside of the United States who are attracted by the size of the U.S. economy and the protection afforded in the United States to intellectual property. The USPTO granted nearly 300,000 patents in 2014, of which the largest share was to U.S. inventors (48%), followed by Japan (18%) and the EU (15%) (Figure O-13). Although the absolute number of USPTO patents granted to U.S. inventors increased by 61% between 2003 and 2014, the U.S. share declined by 4 percentage points in this period. Conversely, the shares of USPTO patents granted to inventors in both developed and developing economies grew.

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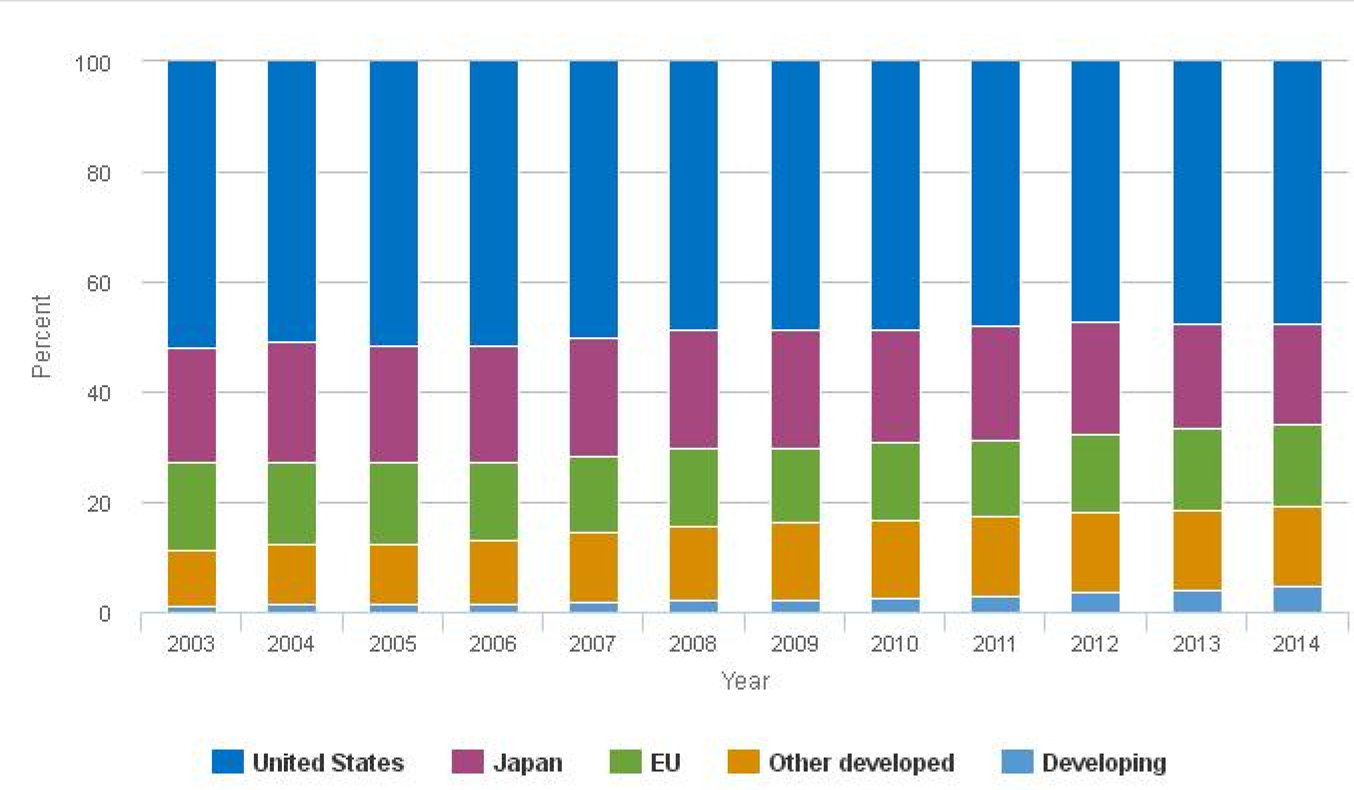
[i] The U.S. data from the Business R&D and Innovation Survey are described in chapter 6. European countries gather data on innovative activities conducted by firms in their Community Innovation Survey. Differences in survey methodologies, industry structure, and cultural differences affect the international comparability of such data. As of fall 2015, U.S. innovation data are not included in the OECD’s cross-country comparisons of innovation rates. For a further discussion on this topic, see Jankowski (2013).

Figure O-13

USPTO patents granted, by location of inventor: 2003–14



EU = European Union; USPTO = U.S. Patent and Trademark Office.

NOTES: Patents are fractionally allocated among regions/countries/economies based on the proportion of residences of all named inventors. The EU includes 28 member countries. See appendix table 6-34. Developed economies are classified by the International Monetary Fund (IMF) as advanced. Developing economies are classified by IMF as emerging.

SOURCES: Science-Metrix; LexisNexis; SRI International.

Science and Engineering Indicators 2016

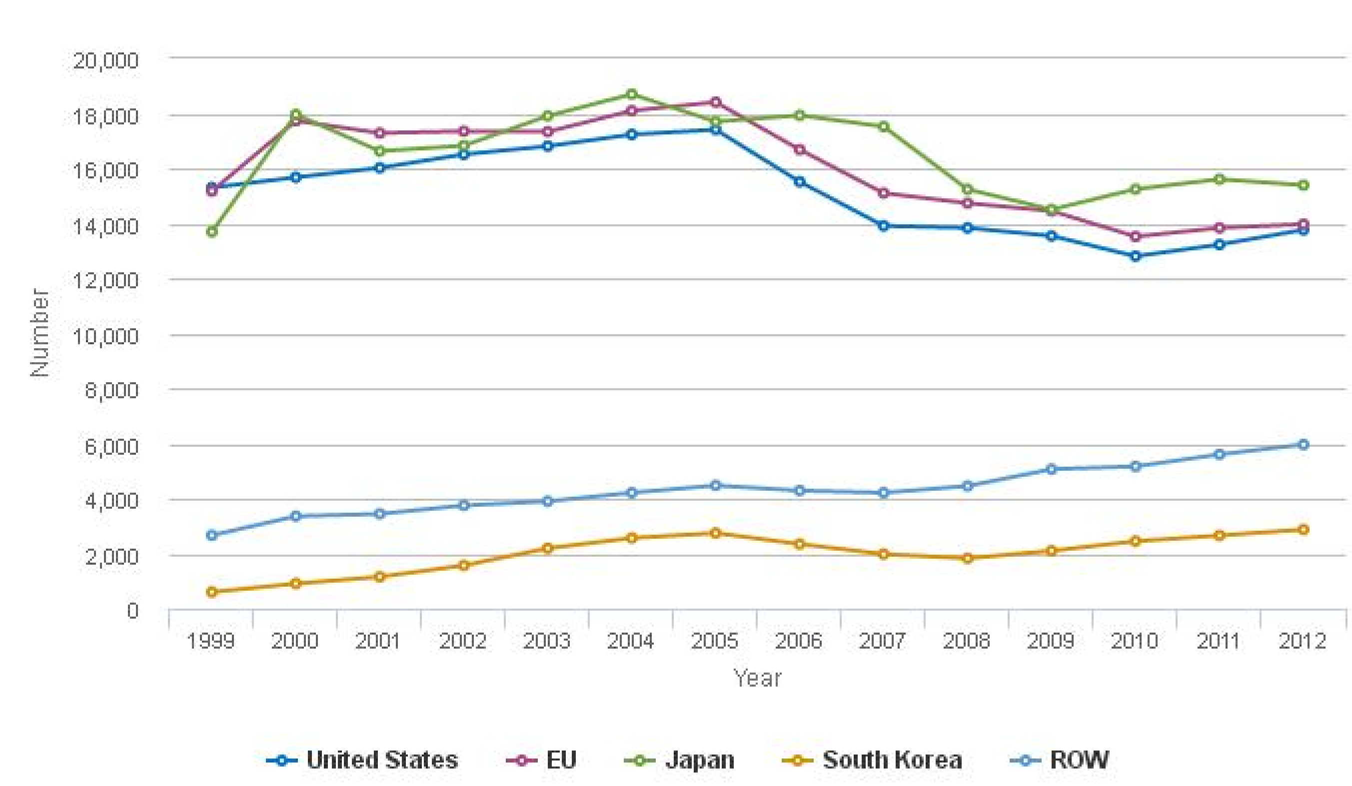
Nevertheless, the shares of U.S. patents awarded to inventors in China (3%) and India (1%) remain modest. In recent years, applications to China's patent office rose much faster than those to the USPTO and other major patent offices (WIPO 2014). Unlike USPTO patents, utility patents in China are not subject to extensive examination, and while the foreign share is growing, patents in China's patent office are overwhelmingly filed by residents of China (Hu 2010).

For any national patent office, data on the numbers of patents granted provide no indication of patent quality. *Triadic patents,* in which inventors simultaneously seek patent protection in three of the world's largest markets—the United States, Europe, and Japan—indicate patents expected to have relatively higher commercial value. In 2012, the number of these triadic patents was estimated to be about 52,000. The shares of the United States, the EU, and Japan stayed roughly similar (at around 30% each) during the 2003–12 period. Although South Korea (6%) and China (4%) increased their respective shares, they receive far fewer triadic patents than the long-standing global leaders (Figure O-14; China is included in the total for the rest of the world).

Overview

Figure O-14

Global triadic patent families, by selected region/country/economy: 1999–2012



EU = European Union; ROW = rest of the world.

NOTES: Triadic patent families include patents applied in the U.S. Patent and Trademark Office, European Patent Office, and Japan Patent Office. Patent families are fractionally allocated among regions/countries/economies based on the proportion of the residences of all named inventors.

SOURCES: Science-Metrix; LexisNexis; SRI International. See appendix table 6-51.

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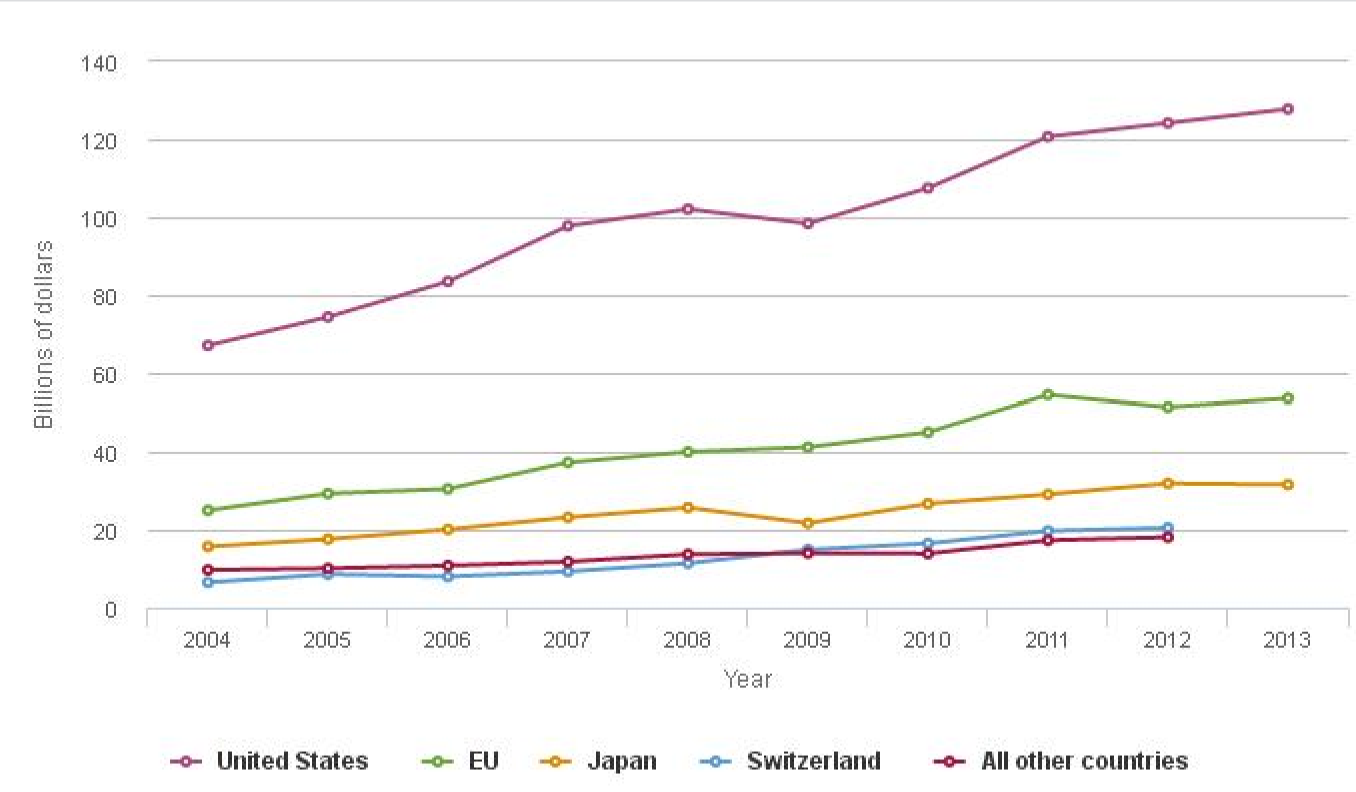
The benefits of innovation are shared when technology spreads from inventors to users. Trade in intellectual property is an indicator of the market-based diffusion of technology and innovation. One measure of intellectual property trade is the cross-border royalties and fees collected for licensing or franchising proprietary technologies. [ii] Although research in recent years has suggested that trade patterns in royalties and licensing fees are affected by different tax treatments, income from intellectual property broadly indicates which nations are producing intellectual property products with commercial value. They generally correspond to the countries and economies holding USPTO and triadic patents. Export income from royalties and fees has exhibited a strongly positive trend over the last decade (Figure O-15), not only among the major players (the United States, EU, and Japan) but also in Switzerland, Singapore, and South Korea.

[ii] For a broader discussion of this trade and the role of intellectual property protection, see The White House (2015, box 7-1).

Figure O-15

Global exports of royalties and fees, by selected region/country/economy: 2004–13



NA = not available.

EU = European Union.

NOTES: EU exports do not include intra-EU exports. Data are not available for all countries for all years.

SOURCE: World Trade Organization, International trade and tariff data, http://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 February 2015.

Science and Engineering Indicators 2016

Despite the rapid increase in many other S&E indicators in recent years, export income for royalties and licensing fees in the developing world is still relatively limited, consistent with these countries' relatively low shares of USPTO and triadic patents. Export income from royalties and licensing fees in 2013 was less than $0.5 billion in India and less than $1 billion in China.

Knowledge- and Technology-Intensive Economic Activity

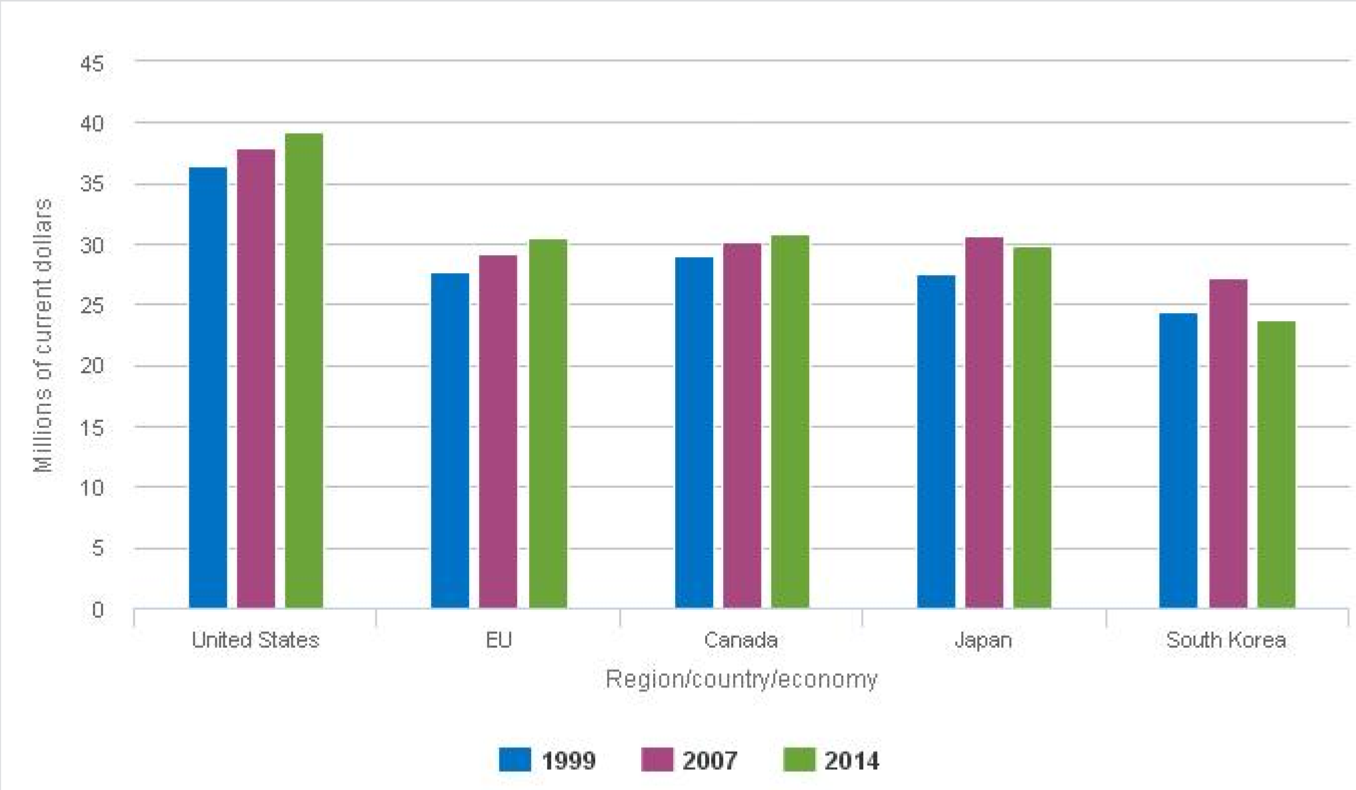
R&D translates not only in articles, patents, and intangibles; with time, its outcomes become a visible part of economic activity in the form of products, services, and processes. S&E knowledge is increasingly a key input to production in the marketplace. Industries that intensely embody new knowledge and technological advances in their production account for 29% of global economic output. They span both manufacturing (e.g., aircraft and spacecraft, computer equipment, communications and semiconductors, pharmaceuticals, and scientific instruments) and services sectors (e.g., education, health, business, financial, and information services) (OECD 2001).

Overview

At 39%, the United States leads the world in the percentage of its GDP that comes from these high-technology (HT) manufacturing and knowledge-intensive (KI) service industries. Historically concentrated in the developed world, these industries typically make up a larger percentage of GDP in developed countries than in developing countries (Figure O-16 and Figure O-17). However, differing growth rates by sectors and by countries and economies as well as globalization of the world economy illustrate how this element of the S&E landscape is shifting globally. Advances in science and technology (S&T) now enable companies to spread knowledge- and technology-intensive (KTI) activity to various locations around the globe and to develop strong interconnections among geographically distant entities. International trade and an interconnected global supply chain link the geographically shifting KTI components together. A country's exports of goods and services produced by its KTI industries indicate its ability to compete in the world market; the supply chain underlying a country's production reflects the interdependence in the production process.

Figure O-16

KTI share of GDP, by selected region/country/economy: 1999, 2007, and 2014



EU = European Union; GDP = gross domestic product; KTI = knowledge and technology intensive.

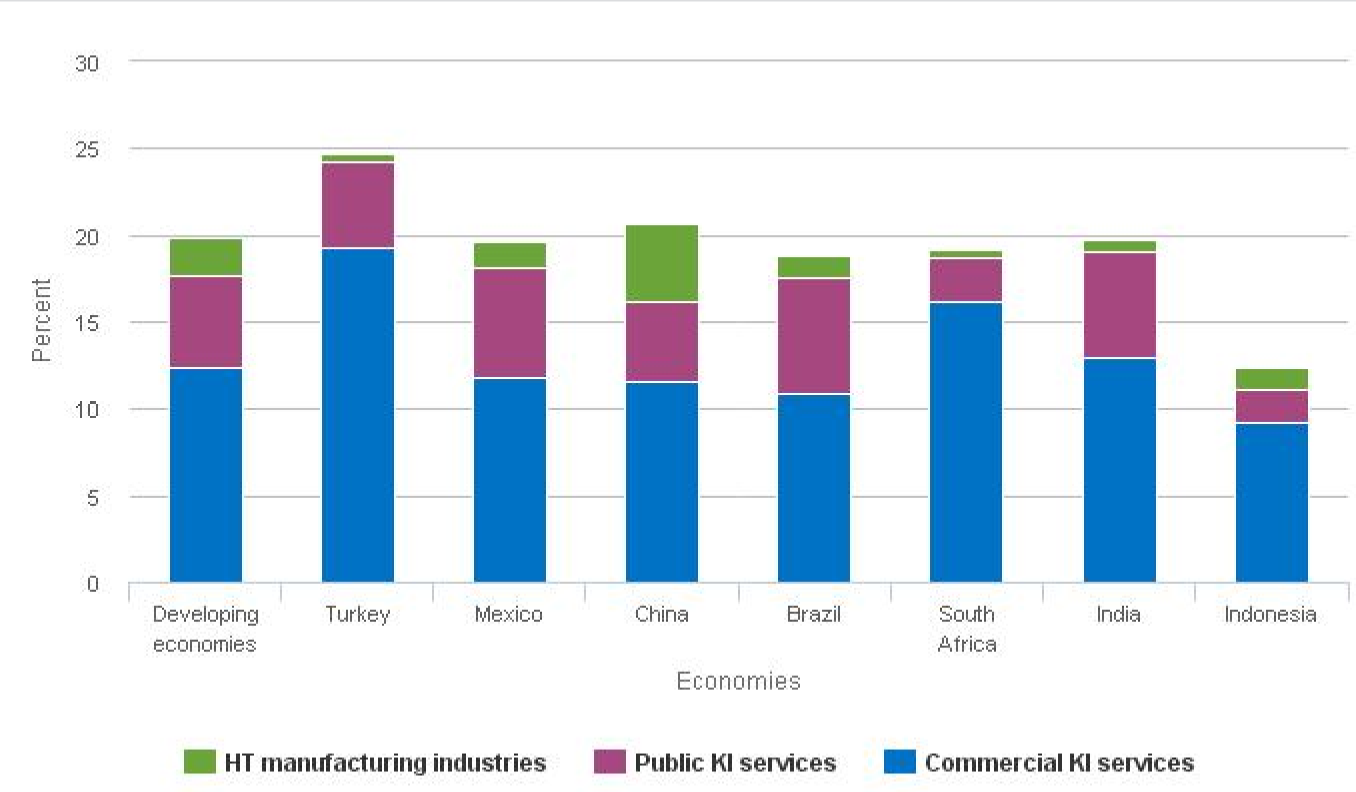
NOTES: KTI industries include knowledge-intensive (KI) services and high-technology (HT) manufacturing industries classified by the Organisation for Economic Co-operation and Development. KI services include business, financial, communications, education, and health. HT manufacturing industries include aerospace, communications and semiconductors, computers and office machinery, pharmaceuticals, and scientific instruments and measuring equipment. Data are not available for EU members Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia.

SOURCE: IHS Global Insight, special tabulations (2015) of the World Industry Service database.

Science and Engineering Indicators 2016

Figure O-17

Output of KTI industries as a share of GDP for selected developing economies: 2014



GDP = gross domestic product; HT = high technology; KI = knowledge intensive; KTI = knowledge and technology intensive.

NOTES: Output of KTI industries is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. KTI industries include KI services and HT manufacturing industries classified by the Organisation for Economic Co-operation and Development. KI services include business, financial, communications, education, and health. Commercial KI services include business, financial, and communications services. Public KI services include education and health. HT manufacturing industries include aerospace, communications and semiconductors, computers and office machinery, pharmaceuticals, and measuring, testing, and control instruments. Developing economies are classified by the International Monetary Fund as emerging markets.

SOURCE: IHS Global Insight, World Industry Service database (2015).

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In HT manufacturing (globally $1.8 trillion in value-added terms in 2014), the United States retains a slim lead as the largest global provider (29%) over China (27%), whose global share rose steeply since the turn of the century. Each country, however, concentrates in somewhat different types of activities. The United States has particular strength in aircraft and spacecraft and scientific instruments (areas where a considerable amount of U.S. business R&D resources are focused). Manufacturing of aircraft and spacecraft involves a supply chain of other HT inputs—navigational instruments, computing machinery, and communications equipment—many of which continue to be provided by U.S. suppliers.[i] China—whose output of HT manufacturing rose by a factor of 10 between 2001 and 2014 (Figure O-18)—is the largest producer of ICT goods (communications, computers, and semiconductors), in which it holds a 39% global share,[ii] and of pharmaceuticals (28%). In both countries, output growth was only briefly slowed by the Great Recession and has rebounded in recent years (Figure O-18). In the EU and Japan, however, HT manufacturing output has stagnated or declined over the same time frame.

Overview

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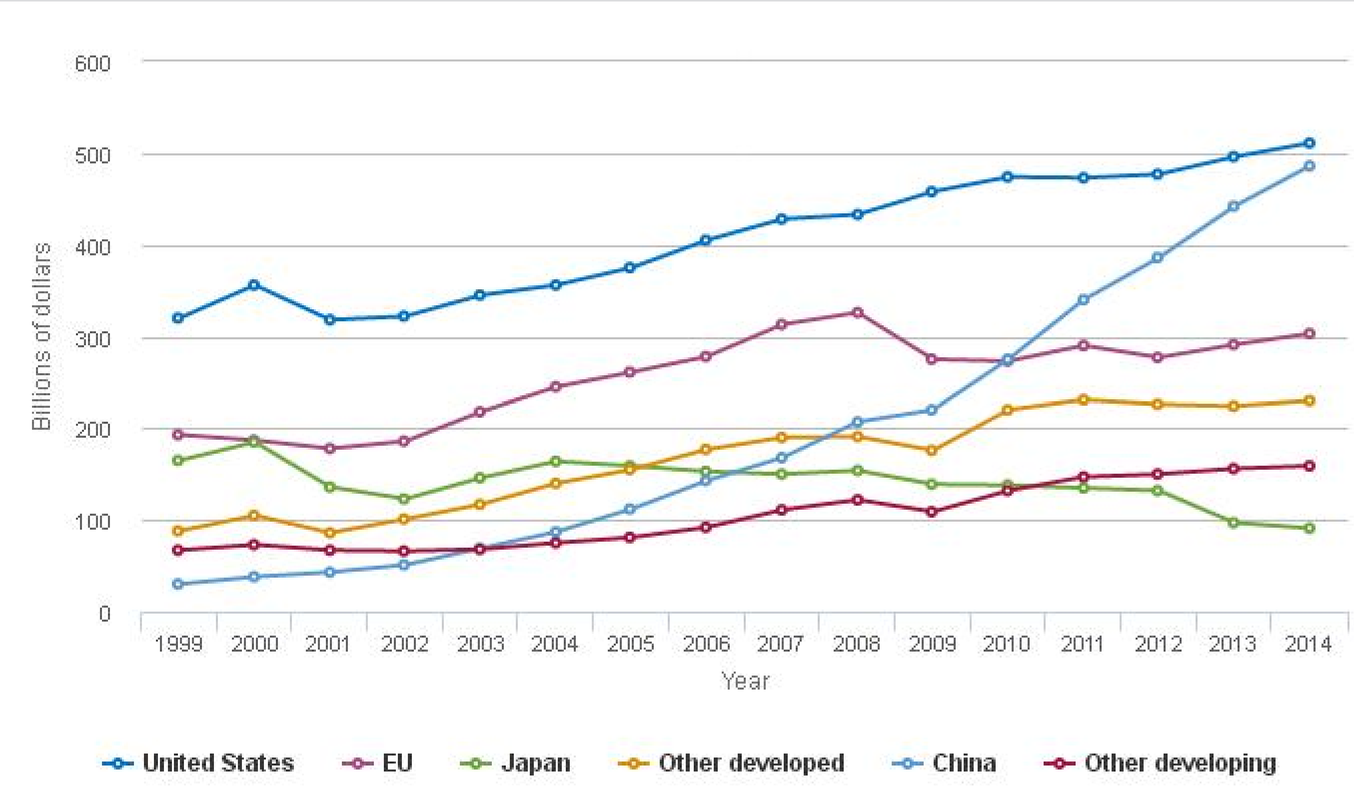
[i] As of 2012, Boeing reported that U.S. companies supply 75% of its supply chain inputs (http://787updates.newairplane.com/787-Suppliers/World-Class-Supplier-Quality).

[ii] The ICT sector includes communications equipment, computers, and semiconductors.

Overview

Figure O-18

Value added of HT manufacturing industries for selected regions/countries/economies: 1999–2014



EU = European Union; HT = high technology.

NOTES: Output of HT manufacturing industries is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. HT manufacturing industries are classified by the Organisation for Economic Co-operation and Development and include aircraft and spacecraft, communications, computers, pharmaceuticals, semiconductors, and testing, measuring, and control instruments. The EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Developed countries classified are those classified as advanced by the International Monetary Fund (IMF). Developing countries are those classified as emerging by IMF.

SOURCE: IHS Global Insight, World Industry Service database (2015).

Science and Engineering Indicators 2016

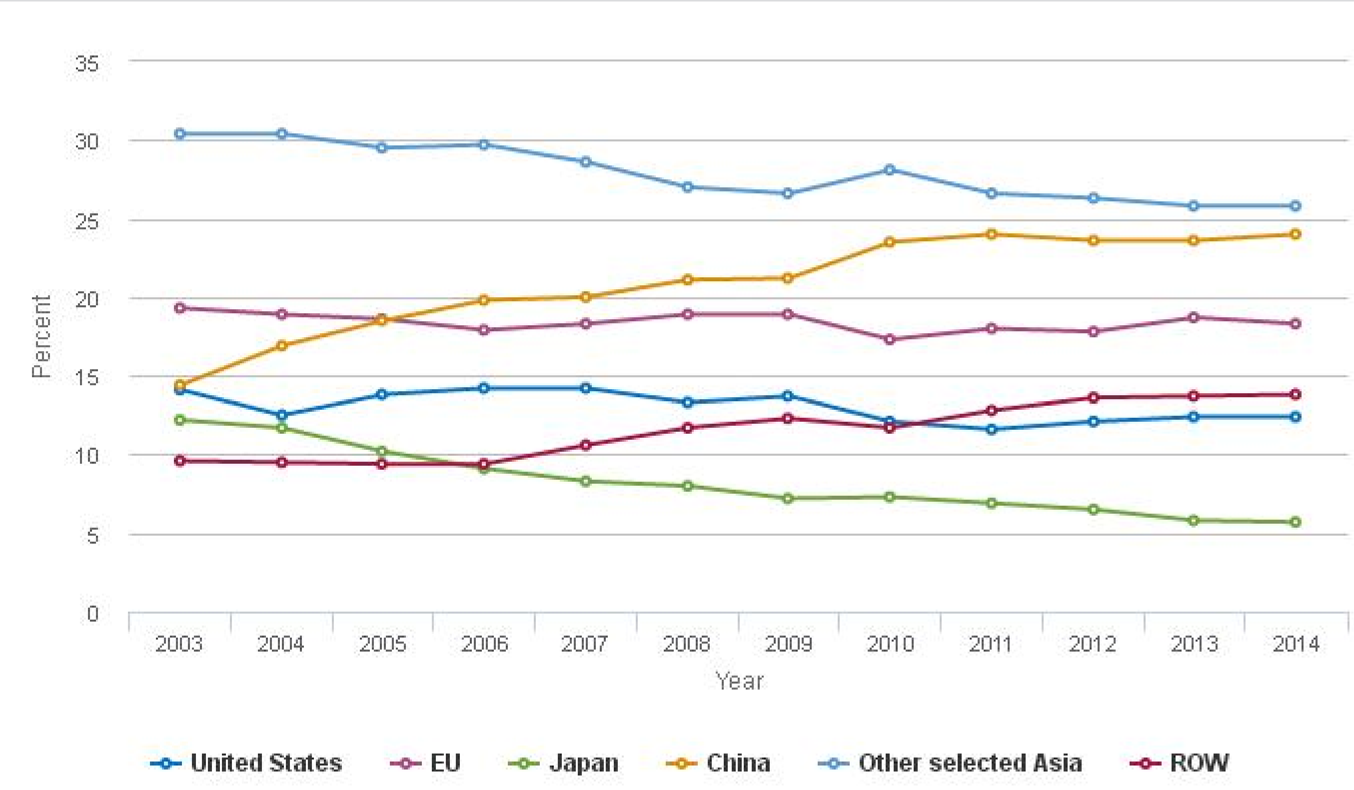
Notwithstanding China's rapid advances, HT manufacturing in this country continues to be heavily dependent on lower value-added activities, such as final assembly. In semiconductors, for example, although Chinese companies have gained global market share, China remains largely reliant on semiconductors supplied by foreign firms for most of its production of smartphones and other electronic products (PwC 2014). In the pharmaceutical sector, output is largely made up of the production of generic drugs by China-based firms and the establishment of production facilities controlled by U.S. and EU multinational corporations (MNCs) (Huang 2015). Many MNCs continue to conduct their higher value-added activities in developed countries because of the greater availability of skilled workers and stronger intellectual property protection. However, China's rapid investments in R&D (much of which is focused on manufacturing), education, and scientific publications may unfold a potential path toward producing more high value-added products, although many social, economic, and political factors in addition to S&E capabilities will likely affect such a path.

Overview

Globally, exports of HT products totaled $2.4 trillion in 2014. ICT products account for more than half of global HT exports, with a large share of ICT concentrated in East and Southeast Asia (China, Japan, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand). China alone accounts for about one-quarter of the global share, but its activities remain focused on low-value activities—final assembly of advanced inputs and components imported from other countries and manufacture of low-technology inputs and components. As a result, China's exports of certain finished products are likely overstated because existing trade statistics include the total market value of finished products. The countries that manufacture and supply advanced inputs and components to China, including the United States, EU, Japan, South Korea, and Taiwan, account for much greater value added than China. In the years since 2007, the growth of HT exports from the rest of the world (Figure O-19), particularly Brazil, the United Arab Emirates, India, and Australia, has been relatively rapid. Vietnam experienced the fastest rate of HT export growth, expanding from $3 billion in 2007 to $39 billion in 2014. Vietnam has become a low-cost location for assembly of cellular phones and smartphones and other ICT products, with some firms shifting production out of China, where labor costs are higher.

Figure O-19

Exports of HT products, by selected region/country/economy: 2003–14



EU = European Union; HT = high technology; ROW = rest of the world.

NOTES: HT products include aerospace, communications and semiconductors, computers and office machinery, pharmaceuticals, and scientific instruments and measuring equipment. China includes Hong Kong. The EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. Exports of the United States exclude exports to Canada and Mexico. Exports of the EU exclude intra-EU exports. Exports of China exclude exports between China and Hong Kong. Other selected Asia consists of Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand.

SOURCE: IHS Global Insight, World Trade Service database (2014).

Science and Engineering Indicators 2016

In addition to HT manufacturing, KTI industries include KI services consisting of commercial services (business, financial, and communication) and public services (education and health).[iii] The largest commercial KI service is business services, which includes the technologically advanced industries of computer programming and R&D services. The large size of business services reflects the widespread practice of businesses and other organizations to purchase various services rather than provide them in-house, particularly in developed countries.

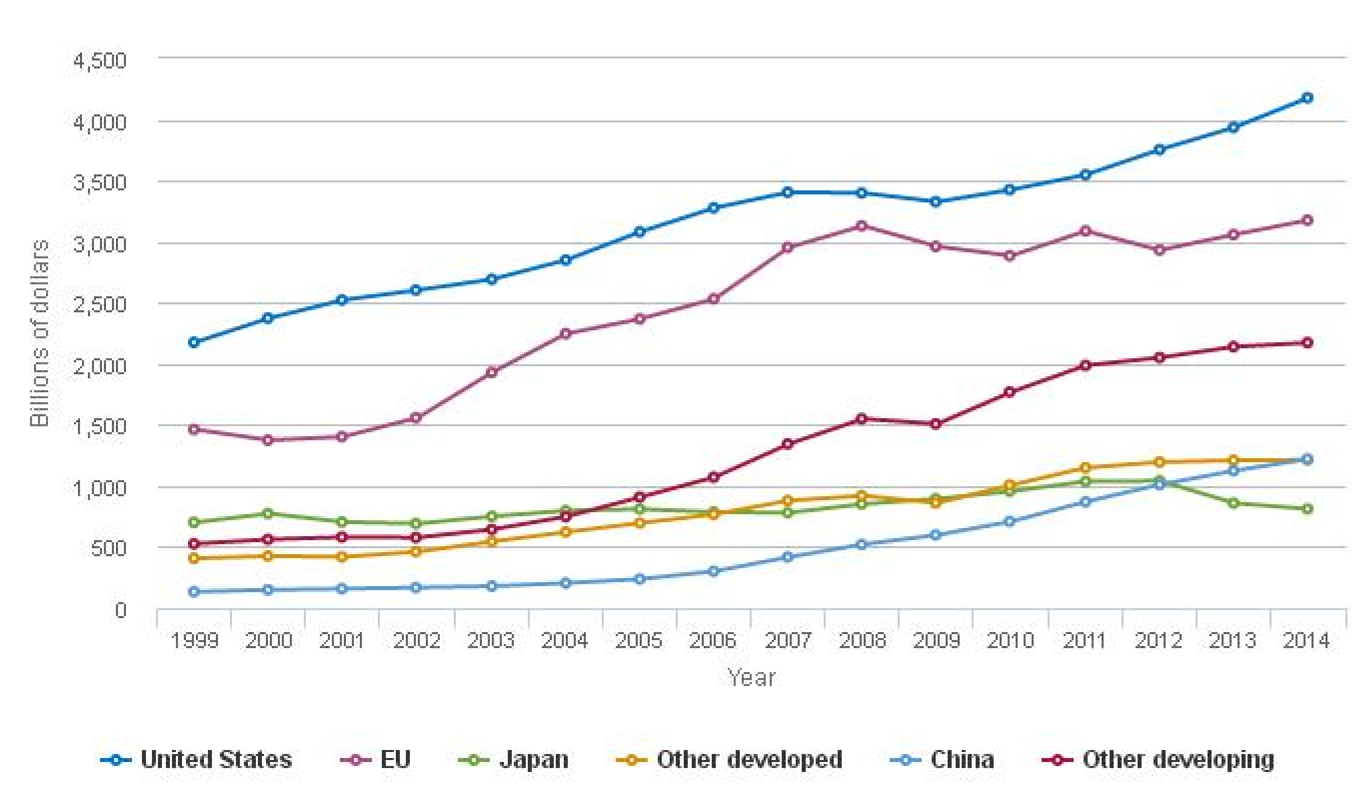
The global output of commercial KI services (which total $12.8 trillion in value-added terms in 2014) is concentrated in the developed world, with the United States (33%) and the EU (25%) accounting for more than half of the global output. Much like HT manufacturing, however, commercial KI services output has stagnated in the EU following the Great Recession due to member countries' overall weak economic growth. In the United States, output rebounded, led by business services and financial services. One source of growth of U.S. business services has been the infrastructure boom in developing countries, which has resulted in the employment of U.S. firms in areas including architecture, engineering, and consulting services. China remains relatively weak in commercial KI services, accounting for 10% of global output, but is making increasingly rapid progress. China's commercial KI services, led by financial and business services, were largely unaffected by the Great Recession (Figure O-20). In the rest of the developing world, Brazil, India, and Russia accounted for growing shares of global commercial KI services output. Brazil's growth was led by financial and information services, and India's growth was led by business services, particularly in computer programming.

[iii] Public KI services—health and education—are much less market driven than other KTI industries. Additionally, international comparison of these sectors is complicated by variations in the size and distribution of each country's population, market structure, and the degree of government involvement and regulation. As a result, differences in market-generated value-added data may not accurately reflect differences in the relative value of these services. The overview presents other indicators for education, such as data on degrees awarded.

Overview

Figure O-20

Value-added output of commercial KI services for selected regions/countries/economies: 1999–2014



EU = European Union; KI = knowledge intensive.

NOTES: Output of knowledge- and technology-intensive industries is on a value-added basis. Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs. The EU excludes Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. China includes Hong Kong. Developed countries are those classified as advanced by the International Monetary Fund (IMF). Developing countries are those classified as emerging by IMF.

SOURCE: IHS Global Insight, World Industry Service database (2015).

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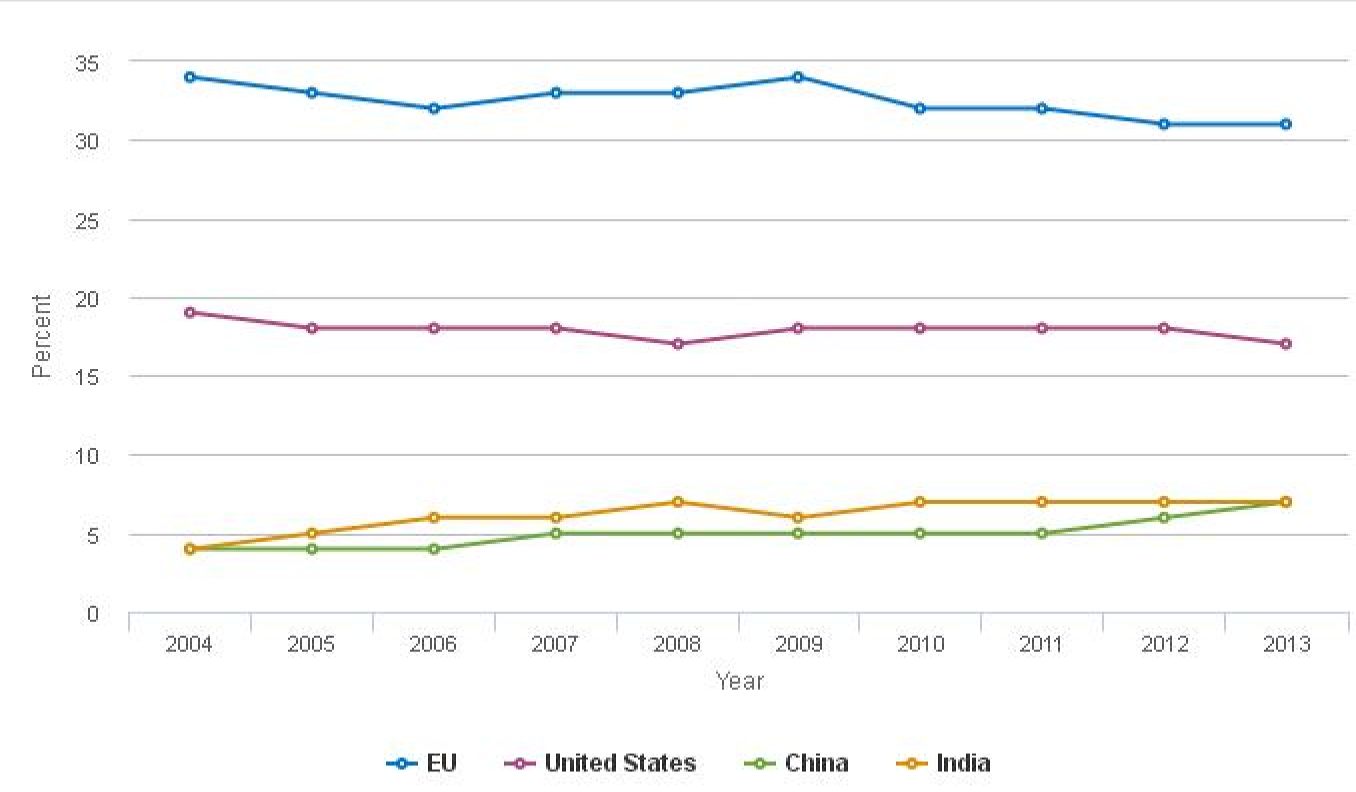
Globally, exports of commercial KI services totaled $1.5 trillion in 2013. The trade of commercial KI services around the world is facilitated in part by the outsourcing activities of multinational corporations, taking advantage of economies with well-educated and multilingual populations. In 2013, the EU and the United States together accounted for just under half (48%) of the exports in commercial KI services; China and India each accounted for 7% (Figure O-21). India, however, represents a considerable share (26%) of global exports in computer and information services, primarily reflecting IT, accounting, legal, and other services provided to developed countries.

Figure O-21

Commercial KI service exports, by selected region/country/economy: 2004–13



EU = European Union; KI = knowledge intensive.

NOTES: Commercial KI service exports consist of communications, business services, financial services, and computer and information services. Financial services includes finance and insurance services. EU exports do not include intra-EU exports.

SOURCE: World Trade Organization, International trade and tariff data, http://www.wto.org/english/res_e/statis_e/statis_e.htm, accessed 15 February 2015.

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Global S&E Activity to Address Energy and Health Challenges

Globally, many S&E activities are focused on addressing urgent challenges in the domains of health and energy. These activities are developing knowledge and technologies that aim to cure diseases, generate clean and affordable energy, and contribute to improved living standards. They are closely linked to scientific R&D, are often global in scope, and involve developed and developing nations, as different nations bring different perspectives and approaches to this endeavor. The United States and the EU, for example, have more-focused efforts on research and knowledge production, whereas China continues to concentrate on later-stage commercial production.

Energy

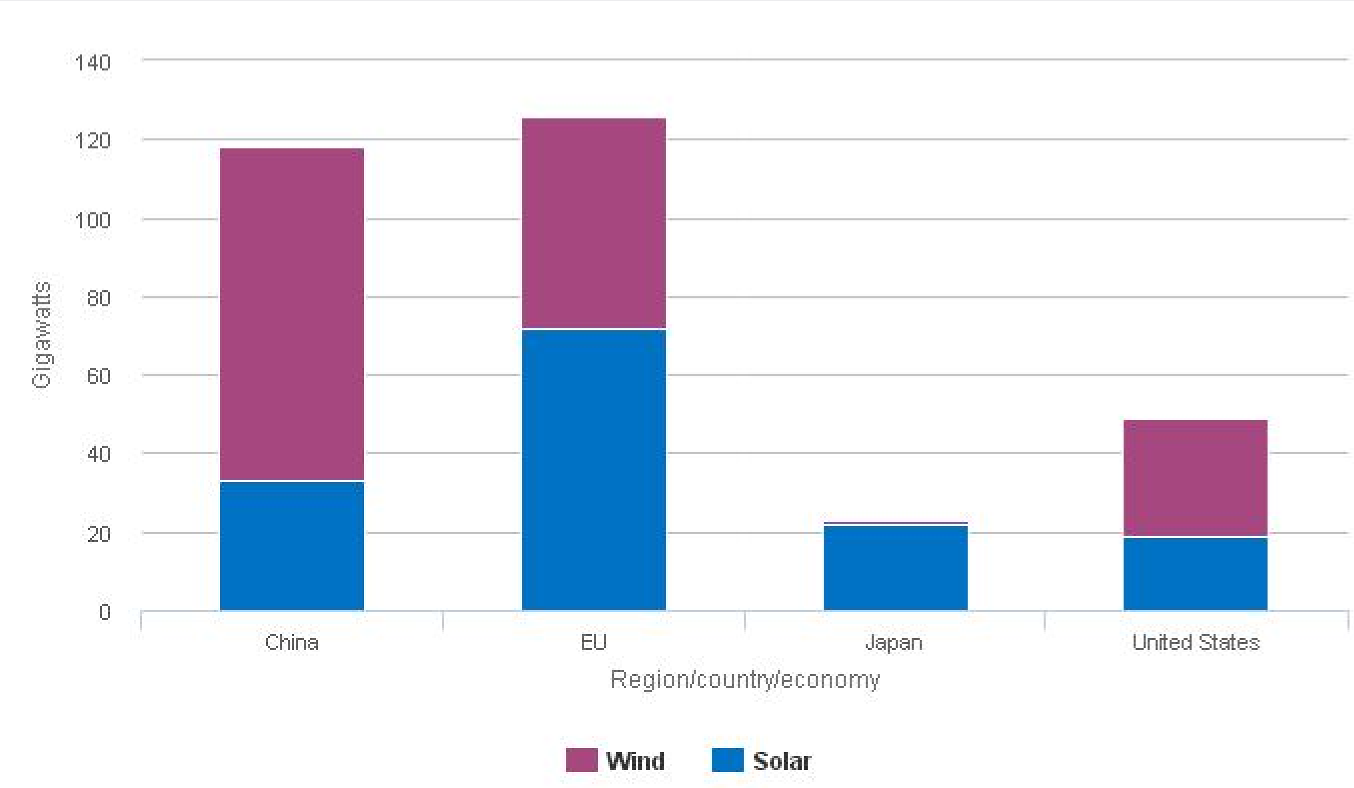
Global activity aimed at generating alternative and affordable energy includes financing, research, patenting, and production in the areas of biofuels, solar, wind, energy efficiency, pollution prevention, smart grid, and carbon sequestration. In response to rising energy demand, volatile costs of fossil fuels, and efforts to reduce emissions of greenhouse gases, governments around the world have enacted various policy measures, including subsidies and tax incentives. Governments have also increased funding to spur both public and private efforts to develop effective and affordable alternative energy sources. Public investment in research, development, and demonstration in alternative energy and other non-fossil fuel technologies totaled an estimated $12.7 billion in 2013. It is led by the EU, with $4.4 billion in investment, followed by the United States ($3.5 billion), Japan ($2.6 billion), and Canada ($0.8 billion).

Globally, among the non-fossil fuel technologies, renewable energy was the largest area of public investment, followed by nuclear energy and energy efficiency. The large role of the public sector in these areas is not surprising, given that these technology areas require establishment of regulatory and safety frameworks as well as large investment for testing and demonstration. EU investment has grown due to increases in funds for carbon dioxide capture and storage, renewables, and energy efficiency. Following the earthquake in northeast Japan in 2011, Japanese investment in nuclear energy has fallen.

With respect to production, commercial investment in clean and renewable energy totals about $281 billion in 2014. China attracts 31% of the global commercial investment in clean energy, followed by the EU (17%) and the United States (15%). Solar and wind are the largest components of renewable energy. In commercial investment for both solar and wind, China is the leading country. The production components resulting from such commercial investment support the generation capacity of renewable energy across the globe. China has become the leader in the production of low-cost photovoltaic modules that convert sunlight into electricity. In the areas of solar and wind generation capacity, an indicator of potential production of renewable energy, China has grown rapidly. Notably, the EU has the highest solar generation capacity, whereas China has the highest wind generation capacity (Figure O-22).

Figure O-22

Cumulative installation of generation capacity of solar and wind, by energy source and selected region/country/economy: 2010–14



EU = European Union.

NOTE: Renewable energy includes biomass and waste, geothermal, hydropower, marine, solar, and wind.

SOURCE: Bloomberg New Energy Finance, http://bnef.com/, special tabulations (2014).

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China's leadership in total commercial investment in clean energy primarily reflects financing of later stages of development in relatively mature areas of clean energy. By contrast, the United States leads in the small share of commercial investment (2% of total commercial investment) that reflects venture capital and private equity investment. These investments primarily focus on emerging and future trends in clean energy technologies. Over the 2010–14 period, smart energy (e.g., digital energy applications, efficient lighting, electric vehicles, efficient smart grid) has been the largest technology area in the United States attracting such investment from all over the world, followed by solar and biofuels.

Patenting in alternative energy and pollution control technologies is also concentrated in the developed world. U.S. inventors were granted 43% of all USPTO clean energy and pollution control patents in 2014, followed by Japan (21%), the EU (17%), and South Korea (9%). Between 2003 and 2014, South Korea's share rose from 2% to 9% due to strong growth in hybrid and electric vehicles, battery, and fuel cell technology. USPTO patents granted to China and Taiwan remain low, with each accounting for about 2% of global share in 2014, up from 1% or less in 2003.

Health

Overview

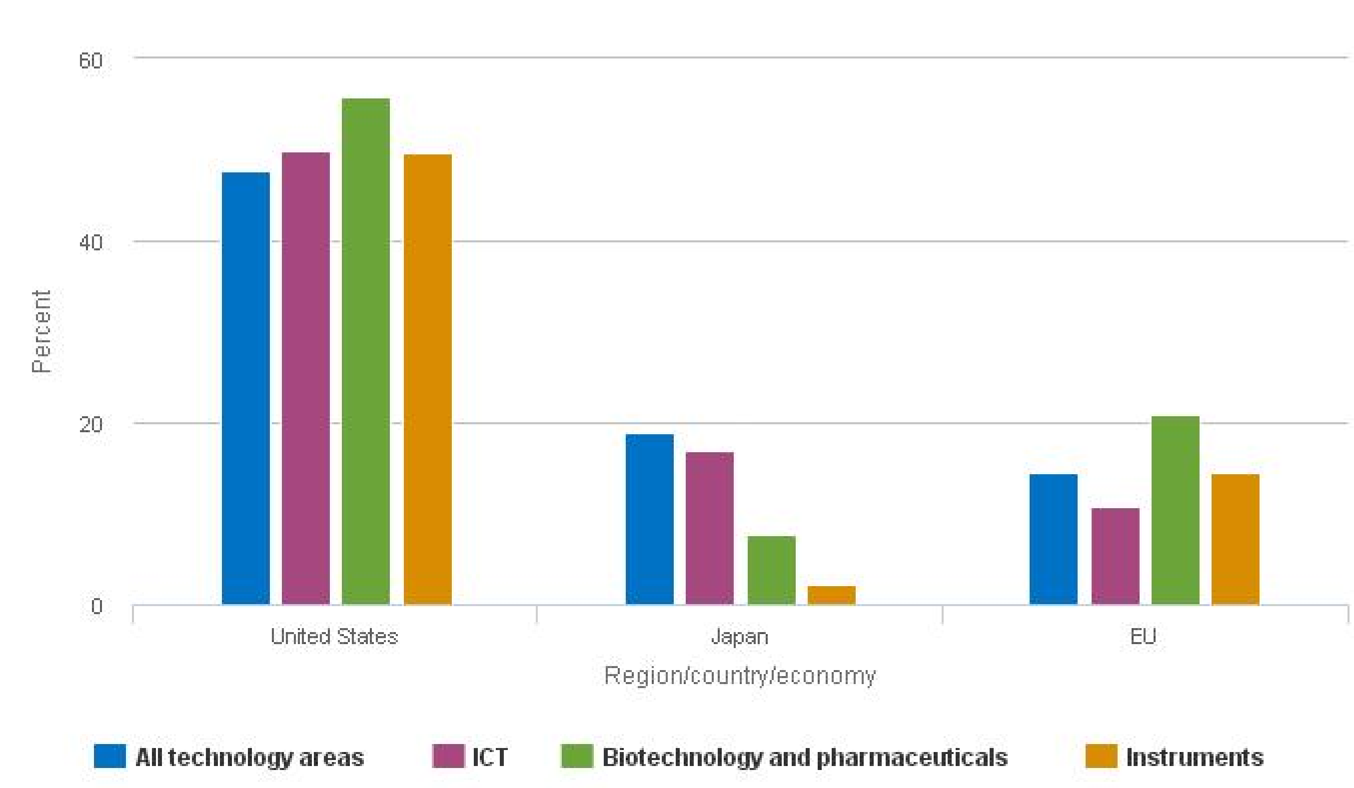
Research in biological and medical sciences and patenting, as well as venture capital and production activity in life sciences, represents global activity related to health. These activities are also spread broadly across the world with a similar degree of specialization between research and production. Research publications reflect contributions to knowledge devoted to health; S&E publications in the United States and the EU are more focused in biological, medical, and other life sciences than the rest of the world. Almost half (48.7%) of the United States' publications are in these areas. Health-related research is an important focus in parts of the developing world as well; India shares the distinction with the United States of having the highest concentration of publications in biological sciences.

Patents are an indicator of the translation of research and other inventive activity into potentially useful innovations. With respect to patenting data from USPTO, the United States and the EU both have greater-than-average patenting activity in biotechnology and pharmaceuticals (Figure O-23), and the EU has an additional concentration in biological materials (see Chapter 6 for detailed data).

Overview

Figure O-23

USPTO patents granted, by selected technology areas for selected region/country/economy of inventor: 2012–14



EU = European Union; ICT = information and communications technologies; USPTO = U.S. Patent and Trademark Office.

NOTES: Technologies are classified by the World Intellectual Property Organization. Patents are fractionally allocated among countries on the basis of the proportion of the residences of all named inventors. ICT consists of computer, semiconductors, telecommunications, digital communications, basic communication processes, and information technology method management. Instruments consists of the following categories: analysis of biological materials, control, measurement, medical technology, and optics.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; USPTO. See appendix tables 6-34–6-49.

Science and Engineering Indicators 2016

However, in terms of production activity, China is now the leader in pharmaceutical manufacturing in terms of quantity of output, and this activity is also growing rapidly in India. The growth in China represents both Chinese firms and outsourced manufacturing by multinational corporations focused primarily on generics. Pharmaceutical manufacturing in India is conducted primarily by domestic firms and also includes the production of generic drugs (Greene 2007).

Summary and Conclusions

The global S&E landscape has experienced dramatic shifts. Over time, the cumulative effect of different growth rates in S&E investment and of different areas of S&E concentration across the globe has led to two outcomes: the "catching up" in particular indicators of S&E activity in parts of the developing world, and the specialized concentrations of global preeminence for developed nations that historically led the global efforts in S&E. As a result, a multipolar world for S&E has emerged after many decades of leadership by the developed world. These developments have taken place in the context of an increasingly interconnected world for S&E activity. Capacity building around the world in R&D and human capital infrastructure, along with improvements in communications technology, has facilitated the interconnected nature and greater international collaboration in S&E activities.

Academic institutions in the developed world continue to be centers of excellence, conducting high-impact S&E research and providing graduate education in S&E to students from across the world. The United States continues to lead in the production of advanced degrees in S&E, while several northern European countries have emerged as centers of high-impact public research, as evidenced by shares of highly cited publications. The impact of S&E research in the relatively new members of the EU has also been growing in recent years, as demonstrated by increased citations from Hungary, Poland, Romania, Slovakia, and Slovenia.

Academic institutions in the developing world have increased their production of graduates with S&E degrees, with China leading the growth in the number of these graduates. R&D expenditures in Asia have also grown rapidly, particularly in China and South Korea. In the United States and the EU, growth has continued but at a slower rate. As a result, China's R&D expenditures are now second only to those of the United States in annual magnitude. China's rapid growth in R&D expenditures and in S&E degrees (both at the bachelor's-degree and doctoral-degree levels) spurred growth in S&E publications.

R&D concentration and intellectual property–related activity are increasingly multipolar; several relatively small economies appear to be specializing in S&E, as evidenced by high rates of R&D intensity in countries such as Israel, South Korea, Taiwan, and Singapore. Commercial S&E activity has a large concentration in parts of East and Southeast Asia; although Japan has been declining in some measures of S&E activities related to knowledge creation (such as shares of S&E publications), the country still rates highly in terms of patents granted. South Korea and Taiwan have experienced rapid growth in patenting and in intellectual property exports.

KTI production and trade account for increasing shares of global output and are closely related to country and regional investment in S&E education and in R&D activity. Production and assembly of high-tech goods have emerged in the developing world, particularly in China, where ICT and pharmaceutical manufacturing have become large shares of global production. Exports of high-technology products are centered in Asia, where China accounts for one-quarter of all such exports, but smaller nations such as Vietnam are expanding rapidly. This production activity, however, often represents the final phase of the global supply chain, where components designed or produced in other countries are transformed into final products.

The developed world, particularly the economies of the United States, the EU, and Japan, maintains the bulk of KI commercial services production and exports, the assignment of patents, and receipts for the use of intellectual property. Intellectual property activities in particular are concentrated in developed economies, both large and small. These developments reflect S&E components of the global value chain, where different regions contribute to global activity based on relative strengths.

This overview has attempted to provide a dynamic summary of the world of S&T as it currently exists and how it has developed over the past decade or more. It has identified some trends that keep working in the direction of

Overview

changing some of the major patterns. Because of the inherent lag associated with the collection and dissemination of high-quality data, the full degree and future direction of such changes become more apparent with the arrival of newer data. As such, the current state of the world depicted in this overview should not be seen as static but rather should be interpreted in the context of a dynamic and integrated world, tied together by global infrastructures and interdependent processes that continue to unfold.

Glossary

Applied research: The objective of applied research is to gain knowledge or understanding to meet a specific, recognized need. In industry, applied research includes investigations to discover new scientific knowledge that has specific commercial objectives with respect to products, processes, or services (OECD 2002).

Basic research: The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study without specific applications in mind. Although basic research may not have specific applications as its goal, it can be directed in fields of present or potential interest. This is often the case with basic research performed by industry or by mission-driven federal agencies (OECD 2002).

Development: Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes (OECD 2002).

European Union (EU): As of September 2015, the EU comprised 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, Organisation for Economic Co-operation and Development data on the EU include all of these 28 members.

Knowledge- and technology-intensive (KTI) industries: Industries that have a particularly strong link to science and technology. These industries include **high-technology (HT) manufacturing and knowledge-intensive (KI) service industries**. **HT manufacturing industries** include those that spend a relatively high proportion of their revenue on R&D, consisting of aerospace, pharmaceuticals, computers and office machinery, semiconductors and communications equipment, and scientific (medical, precision, and optical) instruments (see http://www.oecd.org/sti/ind/48350231.pdf, accessed 25 August 2015). **KI service industries** include those that incorporate science, engineering, and technology into their services or the delivery of their services, consisting of business, information, education, financial, and health services. **Commercial KI services** are generally privately owned and compete in the marketplace without public support. These services are business, information, and financial services.

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